Observational Study

Medicine®

OPEN

Driving scene-based driving errors in brain injury patients and their relevance to cognitive-perceptual function and functional activity level

A cross-sectional study

Myoung-Ok Park, PhD, OT*

Abstract

Driving is an essential activity for community engagement in patients with brain injury. However, brain injury patients have cognitive-perceptual deficits and low independence in daily activities. The aims of this study were to identify the driving errors of brain injury patients and determine their relevance to cognitive-perception function and daily activity level. This study was conducted at a single rehabilitation hospital. Thirty-one brain injury patients were included in the study. The patients underwent a driving-scene-based simulator evaluation in the rehabilitation clinic. Driving errors were checked using automatic software. Perceptual ability was measured using Motor-free Visual Perceptual Test (MVPT) and Cognitive-perceptual Assessment for Driving (CPAD). A linear relationship was found between the driving aptitude score, steering wheel and judgment, simultaneous operation items, total score of road course test, and cognitive-perceptual functions and daily activity levels of the participants ($P<.05$). The general factors that affected driving errors included driving experience, age, part of the hemispheric affected, and presence of vascular injury ($P<.05$). In addition, the Korean version of Mini-Mental State Examination (K-MMSE) score and the CPAD score correlated with driving errors ($P<.05$). The total error score of the participants correlated with the Korean version of the Modified Barthel Index (K-MBI) score ($P<.05$).These findings suggest that driving experience and age have more influence on driving error than perceptual level due to brain damage. In addition, it was found that the basic level of daily living influences overall operating errors.

Abbreviations: CPAD = cognitive-perceptual assessment for driving, K-MBI = Korean version of Modified Barthel Index, K-MMSE = Korean version of Mini-Mental State Examination, MVPT = Motor-free Visual Perceptual Test.

Keywords: brain injury, cognitive-perceptual function, driving errors, functional activity

1. Introduction

Self-driving is an important activity for integrating into the community.[1] Brain injury patients often have difficulty in resuming driving due to a reduced in driving-related cognitive and visual perceptual factors as well as deterioration of physical functions, such as sensory and motor functions.[2] Traffic accidents occur due to various factors, but human errors account for >70% of the accidents.[3] Human errors can be divided into 3 main categories: slips, lapses, and mistakes.[4] In particular, driving error due to cognitive failure is a major impediment to safe driving in stroke patients.[5] Driving is an activity that takes places in a dynamic environment. In order to drive safely, it is necessary to have proper judgment, such as heeding to traffic signals and responding to sudden dangerous situations.[6] Therefore, driving errors due to cognitive-perceptual failure may be an indicator of problems with information processing while driving.[7] Several previous studies have identified driving performance-related problems related to cognitive-perceptual functions.[8–10] For example, Daigneault et al reported that older drivers who have cognitive decline had a higher accident rate.[11] In particular, they argued that diminished executive function influenced risky driving behavior, such as not reducing the speed.[11] Another study analyzed the driving performance skills of brain injury patients using a driving simulator. The results showed that driving performance skill significantly correlated with the results of a neuropsychological test.[12]

Motor-free Visual Perception Test (MVPT) is a sensitive tool for predicting driving performance and has been well known for the prediction of driving ability.[13] It assesses visual perceptive functions, such as spatial-perception, visual memory, visual attention, figure-ground discrimination, and objective-constancy. These components are referred to as the basic perceptive factors for driving.[13] When driving in busy traffic, such as in the city, drivers face a variety of situations and need to process much more information than usual, such as traffic signs, pedestrians, and hazards. For example, a driver must know the sign even if the traffic signal is hidden in the aisle and only half of it can be seen.

Editor: Rocco Salvatore Calabrò.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (no. 2017R1C1B5075476) and Baekseok University research fund.

The authors certified that there is no conflict of interest.

Department of Occupational Therapy, Division of Health Science, Baekseok University, Chungcheongnam-do, Republic of Korea.

* Correspondence: Myoung-Ok Park, Department of Occupational Therapy, Division of Health Science, Baekseok University 76, Munam-ro, Dongnam-gu, Cheonan-si, Chungcheongnam-do, Republic of Korea (e-mail: parkmo@bu.ac.kr).

Medicine (2019) 98:27(e16315)

Received: 11 February 2019 / Received in final form: 26 May 2019 / Accepted: 12 June 2019

http://dx.doi.org/10.1097/MD.0000000000016315

Such competencies are based on visual perception capabilities, such as form-constancy and figure-ground discrimination which are assessed in MVPT sub-items. In addition, a driver must make quick and accurate decisions for a given driving situation which they achieve through attention capture and anticipation.[14] During sudden interruptions during driving, the driver should be able to make an instantaneous decision to slow down the vehicle to avoid accidents; such action is related to higher cognitive functions, such as situation judgment.[15]

Whether a brain injury patient understands a driving situation can be assessed using driving-scene-based assessments, such as a driving simulator. This makes it possible to detect the driving errors of the subject and to assess understanding of the driving situation. Several studies have predicted and analyzed cognitive perceptions that affect driving performance in stroke and brain injury patients.[16–18]. This cause cognitive-perceptual elements are important factors for safe driving. However, until now, only a few studies have examined how the daily activity level of stroke or brain injury patients affects their driving performance. The level of activities of daily living is presumed to be related to the ability to drive because it is a reference to the overall functional level of the patient. Therefore, in this study, we tried to identify the relationship between driving performance errors using driving scenes, cognitive perception functions, and performance of functional activities among stroke patients.

2. Materials and methods

2.1. Participants

This study was a cross-sectional observational study and the participants were recruited from a rehabilitation hospital in Seoul, South Korea. Informed consent was obtained from the study participants who were patients visiting the driving rehabilitation clinic for 3 months. The inclusion criteria were as follows:

(1) patients having a history of onset of stroke or brain injury of >6 months,
(2) patients holding a driving license before the onset of stroke or brain injury and had actual driving experience,
(3) patients with intact physical function of the right side,
(4) patients without reduced vision and hearing impairments,
(5) patients who could follow the instructions, and
(6) patients who agreed to participate in the study.

Among the total number of patients, 4 refused to participate in the study, and thus, a total of 31 stroke patients were enrolled. This study was approved by the local ethics committee and the participants were briefed about the purpose and methods, procedure, and ethical issues based on the Declaration of Helsinki.[19]

2.2. Assessment tools

2.2.1. *Driving simulator based on driving scenes.* To examine the driving performance skill and driving errors, a virtual reality driving simulator was used (GDS-300, Gride space, Seoul, Korea). The hardware of the virtual driving simulator consisted of an auto-system equipped with an automatic transmission. It was equipped with a left turn indicator lever so that the patients with lesions in the left hemisphere could use the vehicle. In addition, 3 screens (center, left, and right) located on the front of the vehicle were installed with 3 beam projectors so that driving courses with the Seoul City Center could appear in the background.

The driving course was designed to show nearby buildings, moving vehicles, traffic lights, and road signs so that the operation can be carried out under conditions similar to those of actual car driving (Fig. 1). The software of the GDS-300 contains an aptitude test item, driving test item, and a driving training program for the driving performance evaluation. In this study, only the aptitude test and road driving test were used. The aptitude test items evaluated basic operation performance based on the motion and cognitive functions during the operation, and included reaction time, steering wheel turning circle test, anticipation test, and a steering wheel and pedal operation test. The maximum score of each item is 100 points.

Reaction time indicates how fast a driver can react to traffic signals. If the red, green, and yellow signals are displayed in

Figure 1. Driving simulator for assessing driving errors.

random order on the screen, the brake should be operated for red, the accelerator for green, and the turn signal for yellow. The faster is the response and response time, the higher is the score. The steering wheel and judgment test involved a disc with a short lever that was continuously rotated counter clockwise and the subject had to manipulate the steering avoiding the stimulation. This test assesses not only the steering wheel operation but also attention and concentration. A higher score is achieved as the number of regular reactions increases. Speed prediction is a test that predicts the speed of a van that has disappeared into a tunnel. The subject cannot see the vehicle when the vehicle enters the tunnel. Therefore, the subject must predict the speed of the vehicle from the left side of the screen to the tunnel side, and turn on the headlamp when the vehicle reaches the endpoint through the tunnel. Simultaneous operation and comprehensive aptitude test is a test that judges reaction time and steering ability at the same time. If an obstacle obstructing the course appears while driving at a certain speed, the driver must operate the steering wheel while avoiding the obstacle. When 3 signals (red, green, and yellow) are randomly displayed in the center of the screen, the driver must correctly operate the brake, the accelerator, and the high beam, respectively. A road test is a program that connects a specific section of the Seoul city with a driving course on a highway. It is designed to evaluate wearing of a seat belt, observation of a directional indicator, violation of a designated speed, and violation of a lane. A score of >80 points is required to pass this test.

2.2.2. Cognitive-perceptual Assessment for Driving (CPAD). CPAD was developed based on the driving aptitude test developed by the Seoul National University Psychology and Psychological Science Research Institute. It was developed as a cognitive perception evaluation tool by the National Rehabilitation Center of South Korea. CPAD can be used for assessing depth perception and sustained attention, and it is composed of the Stroop test, digit span test, field dependence, and trail making test. The scores are checked based on the number of reactions and reaction time. If the total score is >53 points, the participant is judged passable with a cognitive function capable of real driving function; borderline, if scored between 42 and 52 points; and considered inadequate cognitive function if scored <41 points. The reliability of this test is suggested by the Cronbach α value of 0.85.[20]

2.2.3. Korean version of Mini-Mental State Examination (K-MMSE). MMSE, originally developed by Folstein, Folstein, and McHugh in 1975,[21] was modified to K-MMSE by Kang et al[22] This test evaluates basic cognitive functions, and it is widely used in clinical practice. It consists of the following components: orientation, attention and calculation, memory recall, and language. A score of ≥24 is considered normal, 18 to 23 is considered mild cognitive impairment, and ≤17 is considered severe cognitive disorder.[22]

2.2.4. Motor-free Visual Perception Test (MVPT). Bouska and Kwatny developed a standardized assessment tool to assess the visual perception ability in patients with brain damage and stroke. The sub-items are time-space relations, visual memory, form homeostasis, foreground-background discrimination ability, and visual integration. There are 36 items in 6 areas, and the total score is 36 points[23].

2.2.5. Korean version of the Modified Barthel Index (K-MBI). In order to assess the activities of daily living, we used the K-MBI, a standardized Korean version of the 5th edition MBI developed by Shah and Muncer.[24] The sub-items consisted of personal hygiene, bathing, feeding, toileting, staring, dressing, bowel/bladder control, ambulation, transfer. The internal consistency is suggested by the Cronbach α value of 0.841.[25]

2.3. Study procedure

The patients who were referred to the driving rehabilitation clinic in the rehabilitation hospital were eligible for the study. The evaluation was done by an occupational therapist. General interview, K-MMSE, and K-MBI tests were administered to patients who agreed to participate in the study. In addition, CPAD and MVPT tests were performed. In order to minimize bias in the assessment that may occur due to motion sickness or non-adaptive regulation of the driving simulator, the participants were given the opportunity to practice in the simulator. After completing these sessions of basic practice, the participants were tested for driving performance using a virtual driving simulator.

2.4. Data analysis

The general characteristics of the participants were analyzed by the frequency distribution. The driving performance skill and driving errors, cognitive perception function, and daily activities levels were analyzed by frequency distribution and descriptive statistics. The Pearson correlation coefficient analysis was used to determine the correlation between driving performance, cognitive perception, and activities of daily living. Stepwise multiple regression was performed to determine the general characteristics and functional factors that caused driving errors. All data were analyzed using SPSS win 20.0 version. The statistical significance was judged at a 2-way significance level of 5%.

3. Results

3.1. Description of the study participants

Of the total participants, 77.4% were males and 22.6% females. The most frequent age group was the 50s (32.3%), and the highest driving experience was from 21 to 30 years (48.4%). The proportion of patients with left-sided hemiplegia (45.2%) was similar to that with right-sided hemiplegia (41.9%). Cerebral infarction was the most common cause of stroke (51.6%), followed by cerebral hemorrhage (38.7%), and traumatic brain injury (TBI) and hypoxia (9.7%) (Table 1).

3.2. Cognitive-perceptual function and daily activity levels of the participants

Table 2 shows the cognitive-perceptual functions and daily activity levels of the participants. The average CPAD score to evaluate the cognitive perception for driving was 50.48 ± 6.66 points, which indicated a borderline group. K-MMSE test result was showed a score of 27.77 ± 2.28 points, indicating that most of the patients had normal cognitive distribution. The MVPT test score was 30.68 ± 3.70 points, while the K-MBI score was 79.19 ± 18.45 points.

3.3. Driving performance and driving errors of the participants

Table 3 shows the results of driving performance using the virtual driving simulator. In the test for driving aptitude, the speed

Table 1

General characteristics of participants (N=31).

Variables	N (%)
Gender	
Male	24 (77.4)
Female	7 (22.6)
Age (years)	
20~29	6 (19.4)
30~39	2 (6.5)
40~49	9 (29.0)
50~59	10 (32.3)
60~69	3 (9.7)
70~79	1 (3.2)
Driving experience (years)	
≤10	6 (19.3)
11~20	11 (35.5)
21~30	14 (45.2)
≥31	0 (0.0)
Hemiplegic side	
Rt. hemiplegia	13 (41.9)
Lt. hemiplegia	14 (45.2)
Quadriplegia	4 (12.9)
Cause of brain injury	
Infarction	16 (51.6)
Hemorrhage	12 (38.7)
Others (TBI, hypoxic brain injury)	3 (9.7)

TBI=Traumatic Brain Injury.

predicting ability score was the highest at 68.90±15.96 points, the reaction time was 1.25±0.34 points, the simultaneous operation and comprehensive attitude score was 41.35±−19.53 points, and the steering wheel and judgment item score was 39.35±18.24 points. In the road test, 41.9% of the participants were wearing seat belts, while 58.1% were not wearing. Among the participants, 83.9% over-speeded, and 16.1% maintained a normal speed. In addition, 71.0% of the participants did not complete the direction instruction for >11 times, and 29.0% did not complete the direction instruction for 1 to 10 times. The brake reaction-time of the participants was 1.18±0.47 seconds, which is 0.6 seconds slower than the Road Traffic Law standard. In terms of compliance with traffic signals, 48.4% of the participants were compliant, and 51.6% were non-compliant. As much as 61.3% of the participants showed a deviation from the course, 41.9% did not meet with any accidents while driving, 45.2% met with 1 to 5 accidents, and 12.9% met with 6 to 10 accidents. The average total driving score was 74.32±18.32, which was lower than the passing score of 80.

Table 2

Cognitive-perceptual function and daily activity level of participants.

Items	Mean±SD
Cognitive-perceptual functions	
CPAD	50.48±6.66
K-MMSE	27.77±2.28
MVPT	30.68±3.70
Daily activity level	
K-MBI	79.19±18.45

CPAD=Cognitive-Perceptual Assessment for Driving, K-MBI=Korean Modified Barthel Index, K-MMSE=Korean-Mini Mental Status Examination, MVPT=Motor free Visual Perceptual Test.

3.4. Correlation between cognitive-perceptual functions, daily activity levels, and driving ability

Table 4 shows the correlation between driving performance, cognitive-perceptual functions, and daily activity levels of the participants. In the driving aptitude test, the response time showed good positive correlations with the CPAD score (r=0.423, P=.018) and the K-MMSE score (r=0.468, P=.008). Steering operation and judgment scores correlated with CPAD (r=0.495. P=.005), MVPT (r=0.332. P=.048), and K-MBI scores (r=0.416, P=.020). Simultaneous operation and a comprehensive attitude showed a significant correlation with all the items: CPAD (r=0.552, P=.001), K-MMSE (r=0.459, P=.009), MVPT (r=0.375, P=.038), and K-MBI (r=0.374, P=.038). However, speed anticipation did not correlate with any item. The total score of road course test showed a significant correlation with CPAD (r=0.369, P=.041), MVPT (r=0.320, P=.043), and K-MBI (r=0.359, P=.047) scores.

3.5. Results of stepwise multiple regression of factors affecting the driving performance errors

Through a stepwise multivariate regression analysis, we found the general characteristics, cognitive perception level, and activities of daily living that affected the participants' operation errors. The factor affecting the non-use of seatbelt error was cerebrovascular injury (B=−0.287, P=.045). The factors affecting the speed errors were K-MMSE score (B=−0.092, P=.000), and age (B=−0.009, P=.038). Directional errors were mostly affected by the participant's hemispheric lesion (B=14.685, P=.007). The traffic signal compliance error was affected by the participant's driving experience (B=−0.505, P=.044), the number of accidents with driving experience (B=0.730, P=.025), and age (B=0.262, P=.076). The deviation from the course was affected by driving experience (B=−0.048, P=.031), and CPAD (B=−0.037, P=.047). The median involvement was affected by age (B=−0.041, P=.140), and driving experience (B=0.061, P=.324). The total error score of the participants was affected by the K-MBI score (B=−0.702, P=.006) (Table 5).

4. Discussion

This study aimed to assess the driving errors of stroke and brain injury patients using a driving-scene based simulator and identify their relationship with driving performance and perceptive functions and daily activity levels. All the participants were diagnosed with stroke or brain injury and had driving experience before the onset. Their average driving experience was at least 10 years.

Driving performance and driving errors were assessed using a virtual-reality-based driving scene simulator. This driving-scene-based driving simulator has been developed in Korea. The contents of the driving scene examination were designed to examine the driving performance by presenting the test items for assessing the operating performance on a section of the actual downtown of Seoul, Korea. It is found that the speed of stepping on the brake and the accelerator pedal was lowered as a whole (average, 1.25 seconds) when the signal was changed in the driving ability test item. Magister et al suggest that the average brake response rate of normal adults should not exceed 0.9 second in unexpected driving situations.[26] Based on this

Table 3

Driving performance and driving errors of participants.

	Items	Mean ± SD, n (%)	Range
Driving aptitude test	Response time (Sec)	1.25 ± 0.34	0.77–1.92
	Steering operation and Judgment (Score)	39.35 ± 18.24	32.66–46.08
	Speed anticipation (Score)	68.90 ± 15.96	63.05–74.75
	Simultaneous operation and a comprehensive attitude (Score)	41.35 ± 19.53	34.19–48.52
Road-test			
Seatbelt	Wearing	13 (41.9)	
	Non-wearing	18 (58.1)	
Speed limit	Over	26 (83.9)	
	Non-over	5 (16.1)	
Turn signal	Compliance	0 (0.0)	
	Non-compliance 1–20 times	9 (29.0)	
	Non-compliance over 11 times	22 (71.0)	
Traffic signal	Compliance	15 (48.4)	
	Non-compliance 1–5 times	16 (51.6)	
	Non-compliance over 6 times	0 (0.0)	
Brake reaction time (sec)	1.18 ± 0.47	0.62–3.05	
Off course	No	12 (38.7)	
	Yes	19 (61.3)	
Number of accidents	No	13 (41.9)	
	1–5 times	14 (45.2)	
	6–10 times	4 (12.9)	
Violation of central line	No	13 (41.9)	
	Yes	18 (58.1)	
Total score		74.32 ± 18.32	35.00–97.00
Result	Pass	13 (41.9)	
	Fail	18 (58.1)	

criterion, it was found that the response rate of stroke or brain injury patients participating in this study was slower than the average response rate of normal adults. In the steering wheel and judgment items, the participants achieved 39.35 points out of 100 in steering and direction control. This score was lower than the standard cut-off score of 60, indicating that the direction and steering wheel of stroke patients were much worse than those of the normal subjects. The speed predictability of the participants was about 68.90 out of 100 points, and they passed the standard cut-off score of 60 points. Thus, although the ability to predict the speed of an approaching vehicle was not high, it was maintained at a reasonable level. The number of crashes among the drivers with stroke was high due to visual impairment.[27] This is presumed to be because of a delay in the processing of incoming visual information.[28]

In the driving-scene-based operation performance evaluation, errors, such as not wearing a belt seat, over-speed, directional lamp failure, and not heeding to traffic signals were noticed. The correlation between the performance of the participants and the perceived function and activities of daily living was significantly high with the response time, CPAD total score, and K-MMSE score. According to a study by Green, the brake response time includes the mental processing time for recognizing incoming information and the movement time for the actual movement of the responder's muscle.[29] The CPAD and K-MMSE tests applied in this study were related to the perception factor of the mental process time, namely, the ability to re-understand the meaning of sensory information coming from the current driving situation. This suggests that the reaction time was closely related to the driving situation and perceptual information processing time. It

Table 4

Correlation between the driving performance, cognitive-perceptual functions, and daily activity level of participants.

		CPAD		K-MMSE		MVPT		K-MBI	
		r	*P*	r	*P*	r	*P*	r	*P*
Driving aptitude test	Response time	0.423	.018*	0.468	.008**	0.223	.229	0.181	.329
	Steering operation and Judgment	0.495	.005**	0.093	.620	0.332	.048*	0.416	.020*
	Speed prediction	0.131	.482	0.009	.962	0.242	.190	0.288	.116
	Simultaneous operation and a comprehensive attitude	0.552	.001**	0.459	.009**	0.375	.038*	0.374	.038*
Road course test	Total score	0.369	.041*	0.011	.951	0.320	.043*	0.359	.047*

CPAD = Cognitive-Perceptual Assessment for Driving, K-MBI = Korean Modified Barthel Index, K-MMSE = Korean-Mini Mental Status Examination, MVPT = Motor free Visual Perceptual Test.
r = Pearson's correlation co-efficient.
* $P<.05$.
** $P<.01$.

Table 5

Factors affecting driving performance errors in stepwise multiple regression analysis.

Variables of driving performance errors	Independent Variable	B	SE	ß	T	R^2
Belt seat -non wearing	Cause of cerebral lesion	−0.287	0.137	−0.363	−2.098*	0.132
Speed over	K-MMSE	−0.092	0.021	−0.637	−4.387*	0.430
	Age	−0.009	0.004	−0.316	−2.178*	
Turn signal error	Hemiplegic side	14.658	5.015	0.477	2.923*	0.201
Traffic signal error	Driving experience	−0.505	0.239	−0.319	−2.109*	0.321
Rate of Accident	Driving experience	−0.730	1.470	−0.212	−0.496*	0.235
	Age	0.262	0.618	0.162	0.424*	
Off course	Driving experience	−0.048	0.048	−0.319	−0.996*	
	CPAD	−0.037	0.021	−0.499	−1.731*	0.538
Violation of central line	Age	−0.041	0.027	−0.566	−1.529*	0.238
	Driving experience	−0.061	0.060	−0.415	−1.009*	
Total error score	K-MBI	−0.702	0.237	−0.762	−2.965*	0.351

CPAD = Cognitive-Perceptual Assessment for Driving, K-MBI = Korean Modified Barthel Index, K-MMSE = Korean-Mini Mental Status Examination, MVPT = Motor free Visual Perceptual Test.
* $P<.05$.

analyzed the general characteristics, cognitive-perceptual function, and activities of daily living that affect the performance error of participants through stepwise multiple regression analysis.

Errors related to not wearing the seatbelt were affected by the cerebral lesion of the patients. The lower the K-MMSE score and the age, the higher was the episodes of over-speed. This suggests that a lower baseline age of the patient was associated with more chances of impulsive driving contributing to driving errors [30]. It also indicates a problem with the underlying cognitive function in patients with brain damage as they have a tendency to over-speed. This is presumed to reflect the problem of behavioral control, which is again presumed to be related to the cognitive and self-regulation abilities.[31] In addition, Ball et al and Cushman found that poor cognition due to aging and a decline in cognitive information processing capacity tended to deteriorate the ability to make judgments in various driving situations, respectively,[32,33] which supports the findings of this study. The variable affecting the use of turn signal lights appeared to be related to the hemispheric side of the lesions, which is presumed to reflect the problem of slow response to turn signal control caused by unilateral paralysis. Traffic signal compliance errors showed that errors tended to be more frequent when the participant's driving experience was lower. This suggests that patients with brain impairment with lesser experience in driving are less likely to understand the overall traffic signal compliance. On the other hand, the rate of accidents tended to increase as the driving experience decreased and the age increased. Guo et al reported that elderly drivers tend to have a lower quality of driving performance with interfering stimuli than middle-aged drivers.[34]

The quality of driving performance deteriorates due to a decrease in the judgment ability in the driving situation in which the interference stimulus is caused by the degradation of the processing function. The lower the CPAD total score, the higher is the frequency of the course off; and the lesser the driving experience and the age, the higher is the tendency to keep the center line. This suggests that cognitive-perceptual information processing ability has a great influence on driving experience, age, and driving errors. In particular, it has been shown that driving experience is related to driving performance errors and accident rates, which supports the results of the present study.[3,35] In addition, the lower the level of activities of daily living in patients with brain damage, the higher the total errors score. This is because the lower the level of basic activities of daily living, the lower is the functional activity performance.

We were able to gain some insights from this study. Similar to healthy drivers, the factors that affected the driving errors of patients with brain damage were found to be driving experience and age. This suggests that patients with brain injury who have actual driving experience may have better driving performance than patients who have no driving experience due to implicit memory. In addition, young adults are more likely to be accustomed to speeding due to difficulty in controlling impulsivity, and elderly people are more likely to meet with more accidents due to a diminished response. These results suggest that the age of the patients with brain damage should also be considered in driving training. While the cognitive perception skills of brain injury patients, in general, are linearly related to the overall performance of the operation, the driving experience and age were found to be influential factors in the overall driving errors. It was found that driving performance was influenced by the level of functional activity in everyday life. This suggests that driving experience, age, and basic activities of daily living should be considered in addition to focusing on cognitive and perceptual factors when training patients with brain injury in a clinical rehabilitation clinic.

This study has some limitations. Because this was a cross-sectional study conducted for a specific period of time and not a cohort study involving a follow-up, the factors affecting the performance of the entire study group were estimated from a single point of time. In other words, it is impossible to estimate the difference in functional changes affecting the driving errors based on the amount of training and the recovery level according to the rehabilitation period. Therefore, in future studies, it is necessary to compare and quantify the quality of operation and the number of errors depending on the timing of rehabilitation treatment and identify and estimate the various factors affecting the rehabilitation treatment.

5. Conclusions

In this study, we found a linear relationship between driving performance, cognitive perception, and basic activities of daily living in brain injury patients. The factors influencing the actual driving errors were age, cognitive function, unilateral paralysis, driving experience, cognitive perception score, and basic activities of daily living. Rather than the perceptual level owing to brain damage, driving experience and age were more influential on the driving errors. In addition, it was found that the basic level of daily living influenced overall operating errors. Therefore, driving rehabilitation specialists need to perform driving re-training considering the basic characteristics of the patients and the level of functional recoveries in daily life.

Acknowledgments

The author would like to thank Mrs Jin-Ju Kim for helping in data collection.

Author contributions

Conceptualization: Myoung-Ok Park.
Data curation: Myoung-Ok Park.
Formal analysis: Myoung-Ok Park.
Funding acquisition: Myoung-Ok Park.
Methodology: Myoung-Ok Park.
Project administration: Myoung-Ok Park.
Writing – original draft: Myoung-Ok Park.
Writing – review & editing: Myoung-Ok Park.
Myoung-Ok Park orcid: 0000-0002-0200-0421.

References

[1] Mezuk B, Rebok GW. Social integration and social support among older adults following driving cessation. J Gerontol B Psychol Sci Soc Sci 2008;63:S298–303.
[2] Marshall SC, Molnar F, Man-Son-Hing M, et al. Predictors of driving ability following stroke: a systematic review. Top Stroke Rehabil 2007;14:98–114.
[3] Parker D, Reason JT, Manstead AS, et al. Driving errors, driving violations and accident involvement. Ergonomics 1995;38:1036–48.
[4] Gray WD, Sabnani H, Kirschenbaum S. Review of the book Human Error. Int J Man Mach Stud 1993;39:1056–7.
[5] Nouri FM, Lincoln NB. Predicting driving performance after stroke. BMJ 1993;307:482–3.
[6] Ma R, Kaber DB. Situation awareness and driving performance in a simulated navigation task. Ergonomics 2007;50:1351–64.
[7] De Winter JC, Happee R, Martens MH, et al. Effects of adaptive cruise control and highly automated driving on workload and situation awareness: a review of the empirical evidence. Transp Res Part F Traffic Psychol Behav 2014;27:196–217.
[8] Park SW, Choi ES, Lim MH, et al. Association between unsafe driving performance and cognitive-perceptual dysfunction in older drivers. PM R 2011;3:198–203.
[9] Galski T, Bruno RL, Ehle HT. Driving after cerebral damage: a model with implications for evaluation. Am J Occup Ther 1992;46: 324–32.
[10] Stav WB, Justiss MD, McCarthy DP, et al. Predictability of clinical assessments for driving performance. J Safety Res 2008;39:1–7.
[11] Daigneault G, Joly P, Frigon JY. Executive functions in the evaluation of accident risk of older drivers. J Clin Exp Neuropsychol 2002;24:221–38.
[12] Lundqvist A, Gerdle B, Rönnberg J. Neuropsychological aspects of driving after a stroke–in the simulator and on the road. Applied Cogn Psychol 2000;14:135–50.
[13] Mazer BL, Sofer S, Korner-Bitensky N, et al. Effectiveness of a visual attention retraining program on the driving performance of clients with stroke. Arch Phys Med Rehabil 2003;84:541–50.
[14] McCall JC, Trivedi MM. Visual context capture and analysis for driver attention monitoring. In Intelligent Transportation Systems, Proceedings of the 7th International IEEE Conference on; 2004, 332–337.
[15] Kass SJ, Cole KS, Stanny CJ. Effects of distraction and experience on situation awareness and simulated driving. Transp Res Part F Traffic Psychol Behav 2007;10:321–9.
[16] Salthouse TA, Atkinson TM, Berish DE. Executive functioning as a potential mediator of age-related cognitive decline in normal adults. J Exp Psychol Gen 2003;132:566–94.
[17] Dawson JD, Uc EY, Anderson SW, et al. Neuropsychological predictors of driving errors in older adults. J Am Geriatr Soc 2010;58:1090–6.
[18] Innes CR, Jones RD, Dalrymple-Alford JC, et al. Sensory-motor and cognitive tests predict driving ability of persons with brain disorders. J Neurol Sc 2007;260:188–98.
[19] Williams JR. The Declaration of Helsinki and public health. Bull World Health Organ 2008;86:650–2.
[20] Jang SJ, Park SW, Kim DA, et al. Cognitive-perceptual assessment tool for evaluation of driving ability of persons with brain injury. J Korean Acad Rehabil Med 2006;30:128–34.
[21] 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;12:189–98.
[22] Kang Y, Na DL, Hahn S. A validity study on the Korean Mini-Mental State Examination (K-MMSE) in dementia patients. J Korean Neuro-psychiatr Assoc 1997;15:300–8.
[23] Colarusso RP, Hammill DD. Motor-free visual perception test. Academic Therapy Pub 1972.
[24] Shah S, Muncer S, Griffin J, et al. The utility of the Modified Barthel Index for traumatic brain injury rehabilitation and prognosis. Br J Occup Ther 2000;63:469–75.
[25] Jung HY, Park BK, Shin HS, et al. Development of the Korean Version of Modified Barthel Index (K-MBI): multi-center study for subjects with stroke. Korean Acad Rehabil Med 2007;31:283–97.
[26] Magister T, Krulec R, Batista M, et al. The driver reaction time measurement experiences. Innovative Automotive Technologyment – IAT; 2005, 5.
[27] Egly R, Driver J, Rafal RD. Shifting visual attention between objects and locations: evidence from normal and parietal lesion subjects. J Exp Psychol Gen 1994;123:161–77.
[28] Cowan N. Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information-processing system. Psychol Bull 1988;104:163–91.
[29] Green M. How long does it take to stop?" Methodological analysis of driver; perception-brake times. Transportation Hum Factors 2000;2:195–216.
[30] Pearson MR, Murphy EM, Doane AN. Impulsivity-like traits and risky driving behaviors among college students. Accid Anal Prev 2013;53: 142–8.
[31] Cotrell V, Wild K. Longitudinal study of self-imposed driving restrictions and deficit awareness in patients with Alzheimer disease. Alzheimer Dis Assoc Disord 1999;13:151–6.
[32] Ball K, Owsley C, Stalvey B, et al. Driving avoidance and functional impairment in older drivers. Accid Anal Prev 1998;30:313–22.
[33] Cushman L. Cognitive capacity and concurrent driving performance in older drivers. IATSS Research 1996;20:38–45.
[34] Guo F, Klauer SG, Fang Y, et al. The effects of age on crash risk associated with driver distraction. Int J Epidemiol 2017;46:258–65.
[35] Blaauw GJ. Driving experience and task demands in simulator and instrumented car: a validation study. Hum Factors 1982;24:473–86.