Exploratory` study on driving ability of people with schizophrenia: relationships among cognitive function, symptoms, and brain activity

Author names

Hiroki Okada[a], Takafumi Morimoto[b], Nozomu Ikeda[b]

Affiliations

[a]Department of Rehabilitation of Sciences, Hokkaido University, Sapporo, Hokkaido, Japan
[b]Department of Occupational Therapy, School of Health Sciences, Sapporo Medical University

Corresponding author

Hiroki Okada
Department of Rehabilitation of Sciences, Hokkaido University, Sapporo, Kita 14-jo Nishi 5-chome, Kita-ku, Sapporo, Hokkaido, Japan
Email: 17S3015@g.iuhw.ac.jp
Phone: +81-011-716-3335
Fax: +81-011-706-2092
E-mail: 17S3015@g.iuhw.ac.jp

Abbreviations[1]

[1]fNIRS	Functional near-infrared spectroscopy
PANSS	Positive and Negative Syndrome Scale
SDLP	Standard deviation of lateral position
TMT	Trail-Making Test
WMS-R	Wechsler Memory Test–Revised
ZMT	Zoo Map test

ABSTRACT

Background: This study aimed to examine the relationships among cognitive function, symptoms, prefrontal activation, basic driving skills, and collision risk factors using a hazard prediction task in simulated driving.

Methods: Participants included 42 people with schizophrenia aged 20–50 years who had actual experience of driving. The Trail making test (TMT) A and TMT-B, Wechsler Memory Test–Revised (WMS-R), and Zoo Map test (ZMT) were used to evaluate cognitive function. Positive and negative syndrome scale was used to assess symptoms, and brain activity was assessed by evaluating cerebral blood flow during a visual working memory task using functional near-infrared spectroscopy. Driving tasks that tested basic skills, such as brake reaction, steering wheel skills, and standard deviation of lateral position, were analyzed using multiple regression analysis. Three hazard prediction tasks were performed using discriminant analysis.

Results: Brake reaction associated with cerebral blood flow and TMT-A. Steering wheel skills associated with WMS-R, driving experience and depression. Significant differences were found between the collision and noncollision groups in the hazard prediction task, as shown by the ZMT, driving experience, and brake reaction.

Conclusions: Brain activity in the frontal lobe during a desk task may be useful data for

driving assessment. Assessment of processing speed and learning ability may be particularly important in the evaluation of basic skills for safe driving. In addition, for people with schizophrenia, foresight, as represented by proactive planning, experience, and quick braking may be an essential characteristic to anticipate danger and react quickly enough to avoid collisions.

Keywords:

driving ability, brain activity, processing speed, executive function, quick braking, driving experience

1. INTRODUCTION

Car is undoubtedly an important means of transportation in today's society. This is also true for individuals with schizophrenia. However, just as for dementia and stroke, schizophrenia is a disease for which driving is regulated via laws and guidelines internationally. At the same time, the question arises regarding whether schizophrenia has such an impact on driving skills that these individuals can no longer be considered responsible for driving during treatment or after disease remission.

Studies focusing on the driving capabilities of individuals with schizophrenia are sparse. Most studies assessing the driving capacity of these individuals gauge their cognitive function and psychomotor abilities using instruments such as the Act and React Test System (ART-90) and the Vienna Test System (VTS), thereby forecasting their safe driving potential (Brunnauer et al., 2004; Segmiller et al., 2017; Garebe et al., 1999). According to Brunnauer (2004), only 32.5% of inpatient schizophrenic people with schizophrenia successfully completed the test assessing crucial cognitive functions for driving without significant deficits. In 2017, Segmiller noted that over half (58%) of the people with schizophrenia exhibited deficits in psychomotor abilities integral to driving. Garebe (1999) determined that only a small fraction of the participants (10.7%) cleared all assessments without notable errors.

Based on the abovementioned findings, it might appear that a consensus has been reached, suggesting that a large proportion of individuals with schizophrenia lack the skills required for safe driving. However, it is imperative to note that only people admitted to hospitals were eligible. Post recovery, there is a potential for enhancement in both cognitive and requisite psychomotor skills for driving, which paves the way for further discussion (Torgalsbøen et al., 2023; Segmiller et al., 2017 Geiger et al., 2007). Moreover, these studies steer clear of a direct evaluation of driving capacities, such as ART and VTS, instead deeming those with cognitive and psychomotor ratings falling 1SD below the norm as lacking in driving prowess. There is a gap in examining how these cognitive function correlate with real-world driving, such as braking reaction, maneuvering, and accident-avoidance skills, and identifying which cognitive deficiencies increase accident risks.

At present, direct evaluation of driving proficiencies and accident tendencies among people with schizophrenia is confined to studies employing simulators (Wylie et al., 1993; St. Germain et al., 2005; Fuermaier, et al.,2019). A comparative study involving 22 people with schizophrenia and 16 healthy individuals revealed that the former group had a higher standard deviation of lateral position (SDLP) and exhibited delayed braking responses to red signals than the latter group (Wylie et al., 1993). Another

simulator-based study executed on a conventional computer demonstrated that compared with 25 healthy participants, 12 people with schizophrenia had diminished standard deviation of lateral position (SDLP) (St. Germain et al., 2005). However, due to the use of equipment with low authenticity of these simulators operating on singular PC display devoid of motion dynamics during driving sessions, the study results remain questionable results. Their lack of fidelity might compromise the precision in gauging driving proficiencies evaluation (Lee et al., 2002). In contrast, more recent investigations using a high-fidelity and advanced simulators have reported negligible differences in braking patterns or accident rates between people with schizophrenia and healthy individuals. Interestingly, healthy individuals exhibited poorer SDLP metrics. Therefore, there is an urgent need to perform more number of studies to objectively evaluate the driving ability of people with schizophrenia. Currently, no single assessment can be used to accurately predict the driving ability of people with mental illness (Unsworth et al., 2012; Dun et al., 2020). For objective assessment of the driving ability of people with schizophrenia, it is very important to examine the relationship among cognitive functions, symptoms, and driving skills, such as individual braking response and SDLP. In the present study, we used a high-fidelity and advanced driving simulator, which has recently become the standard for driving ability assessment. This

tool was used to examine the relationship among cognitive functions, symptoms of schizophrenia, and the most basic skills for safe driving—brake control, steering wheel skills, and SDLP. Furthermore, we examined the traits of individuals more susceptible to accidents, considering their basic driving abilities, especially in contexts like city driving where evading potential hazards and mishaps is essential for safe navigation. Because this study aimed to objectively evaluate driving ability, we also examined the relationship between cerebral blood flow and each driving skill during a desk-based neuropsychological test using functional near-infrared spectroscopy (fNIRS) to investigate the possibility of using data obtained by measuring desk-based brain function for driving evaluation.

2. MATERIALS AND METHODS

Participants diagnosed with schizophrenia based on the International Classification of Diseases, 10th Revision (ICD-10) in a major city in Japan were included. Participants with a substance use disorder, neurological disorder, intellectual disability, or severe orthopedic disorder were excluded. Their diagnoses and exclusion criteria, as determined by their primary physicians, were further confirmed through a review of their medical records. Participants aged 20–50 years with actual driving experience in

the past year were included. The sample size was determined by power calculation, with $p < 0.05$, power = 0.35, assuming performance of multiple regression analysis assuming approximately 5–6 independent variables. Positive and negative syndrome scale (PANSS) was used to assess positive symptoms, negative symptoms, disorganized symptoms, excitement, and depression (Kay et al., 1987). Assessments using PANSS were conducted by seasoned occupational therapists and clinical psychologists holding doctorate degrees and having prior expertise in symptom evaluation. The mean intake of antipsychotics was calculated using chlorpromazine equivalence (Inagaki and Inada, 2022).

The cognitive functions related to driving were evaluated by the following tests: i) attentional function, assessed by visual processing speed on the Trail-Making Test (TMT-A) (Reitan, 1958); ii) memory function, assessed by visual memory visual reproduction the Wechsler Memory Test–Revised (WMS-R) (Wechsler, 1987); and executive function assessed by set-shifting and inhibitory function on the TMT-B (Reitan, 1958) and by planning on the Zoo Map test (ZMT) (Williams, 1991). These test batteries have been linked to driving (Novack et al., 2006; Richardson and Marottoli, 2003; Motta et al., 2014).

The fNIRS cerebral blood flow measurements were made in the frontal lobe as the

region of interest, and the neuropsychological test was a visual working memory task. Decreased cerebral blood flow in the working memory task represents reduced frontal lobe function (Kumar et al., 2021). Because reduced frontal lobe function has been found to be associated with driving skill, we hypothesized that this function may be a relevant factor in predicting driving skill and performance (Starkey and Isler, 2016). The research protocol was approved by the Ethics Committee of the Graduate School of Health Sciences, Hokkaido University. All study participants provided written informed consent. In particular, before the study began, the experimenter explained that if participants experienced driving simulator sickness (e.g., motion sickness or dizziness) during the task, they could discontinue the experiment. Moreover, the useful field of view (UFOV) has been recognized as a pertinent measure for gauging its association with driving capabilities (Novack et al., 2006.) Individuals with schizophrenia find this task extremely difficult to perform. (Gray et al., 2014). However, we could not include UFOV in our assessment due to its high cost. Although, TMT is not a complete substitute for UFOV, we employed TMT related to UFOV for evaluating visual information processing (Selander et al., 2020).

2.1 fNIRS, working memory task, and cerebral blood flow analysis

In the working memory task, a wearable optical topography system (WOT-110, Hitachi, LTD, Japan) was used for fNIRS measurements. Figure 1 shows the location of the sensors. This wearable headset device contained 16 channels of probes corresponding to the frontal lobe points. The sampling interval Δt_ was set at 0.2 seconds.

An overview of the experimental environment and the working memory task is shown in Figure 2. The experiment was conducted in a quiet, private room where all fluorescent lights were turned off and ambient light was blocked by a light-shielding curtain so that the participants could concentrate on their work. A stimulus presentation system (Hitachi) was used for the working memory task. The rest period before and after the task was set to 30 seconds, and the task duration was set to 10 seconds. A total of 20 trials were added and averaged to obtain the cerebral blood flow.

Relative changes in HbO2 from baseline at the beginning of the measurement period were calculated using platform for optical topography analysis tools (POTATo). Concentration values were calculated using a modified Beer–Lambert law and expressed as molar concentration (mmol/L) multiplied by optical path length (mm). Motion artifacts were identified and corrected using wavelet-based methods (Molavi and Dumont, 2012). Physiological noise reduction was achieved by removing slow frequencies and physiological noise (e.g., respiration) using a bandpass filter (third-

order Butterworth bandpass filter, 0.01–0.3 Hz) (Pinti et al., 2018). The analysis in this study focused on oxygen-hemoglobin (Strangman et al., 2002) (Plichta et al., 2006).

2.2 Driving simulator

In this study, experiments were conducted using a Honda driving simulator (Figure 1) (HONDA, Ltd., Japan). The driving simulator is an immersive system that covers the driver's field of vision with three 42-inch screens with a viewing angle of 172°. Based on Wynne's (2009) research, the simulator was confirmed to possess a fidelity ranging from moderate to high.

2.3 Driving skills task

we focused on assessing the most basic driving skills: i) brake reaction control, ii) curve-driving steering wheel operation, and iii) high-speed driving SDLP. In the brake reaction control task, a vehicle suddenly jumped out at 200.7 m when driving at 50 km on a 227-m-long course and the driver was asked to brake as quickly as possible six times. The distance between the vehicle and the obstacle was 26.9 m. For the curve-driving steering wheel maneuver task, a curve with R = 40 was driven at a speed of 50 km/h, and the left and right sides were combined 12 times. For the high-speed driving

SDLP task, the task consisted of driving at 100 km on a straight road for 10 minutes. The road width was 4 m. The average brake reaction time was extracted from the brake task. For stability during curve driving, the coefficients of variation of the steering wheel angle (rad) were determined, and for the high-speed driving SDLP task, the coefficient of variation of SDLP was extracted.

For the urban driving task, a course was set up that reproduced hazardous situations typical of collisions (Figure 3). The participants were instructed to "drive as usual, obeying legal and traffic rules." All participants were given a 10-minute practice run before performing these tasks.

2.4 Statistical analysis

First, a correlation analysis was performed to evaluate the relationships between basic driving skills and cognitive function, symptoms, cerebral blood flow, and basic attribute. To clarify the characteristics related to the three basic driving skills (braking reaction, steering wheel stability, and SDLP at high speed) were analyzed using the Pearson product-moment correlation coefficient. In addition to medication dosage, driving experience, as a basic attribute, was selected as a variable because driving experience is likely to influence driving skills, and this possibility may also apply to

people with schizophrenia (Upahita et al., 2018). Driving experience (in years) refers to the duration in which a person possessed a personal car (encompassing vehicles owned by family members) and utilized it for crucial daily tasks, such as employment, purchasing goods, and recreational activities, at least once a week. After the correlation analysis, we conducted a forward selection in multiple regression analysis on variables with $p < 0.1$ to exploratively examine the best contributing factors and models for each driving skill by referring to the methods of Katz et al. (2011).

The second analysis involved the examination of the clinical characteristics of the group that had an accident (collision group) and did not have an accident (noncollision group) during the urban driving hazard prediction task. Mann–Whitney U test was used to compare the differences between the collision and noncollision groups during the hazard prediction task. Moreover, basic driving skills—brake reaction control task, curve-driving steering wheel operation task, and high-speed driving SDLP task—affect collisions during the hazard prediction task while driving in urban areas were also examined. Using the variables that became significant in the analysis of A Mann–Whitney U test, discriminant analysis was aimed to identify factors distinguishing the groups with and without accidents.

3. RESULTS

Of the initial 46 participants, one was omitted because of rheumatism and another due to alcohol addiction in the past. Furthermore, simulator-induced discomfort prevented two participants from completing the driving test, which resulted in their exclusion from the study. The basic attributes of the participants and the descriptive statistics parameters for the remaining 42 participants are presented in Table 1. In terms of medication, 95% of the participants were stably medicated with second-generation antipsychotic (SGA). Concurrently, 5% were on SGA and first-generation antipsychotic, 19% on anxiolytics, and 88% maintained stability with hypnotics.

3.1 An exploratory analysis of factors associated with basic driving skills using multiple regression analysis

First, correlation analyses were performed to determine the associations among foundational driving abilities, cognitive function, symptoms, cerebral blood flow, driving experience, and medication dosage (Table 2). A correlation was observed between brake responsiveness and TMT-A, TMT-B, and cerebral blood flow ($p < 0.1$). Steering tasks were associated with TMT-A, WMS-R, disorganized, and depression. However, SDLP showed no significant correlation with any of the measured factors.

Next, forward selection multiple regression analysis was performed based on the results of the correlation analysis. Table 3 depicts the multivariate regression analysis outcomes. For the brake reaction, the variables TMT-A, TMT-B, and excited were incorporated. The most significant factor in this model was cerebral blood flow, followed by TMT-A, enhancing its explanatory power. For steering wheel tasks, variables such as driving experience, TMT-A, WMS-R, ZMT scores, disorganized, and depression were considered for regression analysis. The most influential factor in this context was WMS-R, with driving experience and depression also adding significant explanatory power. The correlation analysis did not reveal any significant variables for SDLP with a p-value of <0.1; hence, multivariate regression analysis was not performed.

3.2 Examining factors influencing collision risks during urban driving: A comparative study of groups with and without collisions

The results of the collision and noncollision groups comparison are documented in Table 4. ZMT, driving experience, and brake reaction time significantly differed between the collision and noncollision groups. Variables demonstrating these differences were subjected to discriminant analysis, the results of which are listed in

Table 5. These variables were proven effective in distinguishing between groups with and without accidents. Table 6 present the prediction accuracy of the model for the collision and noncollision groups. The predictive accuracy of this model was 78.6%. Moreover, cross-validation of the results was performed that found similar to original classification results.

4. DISCUSSION

In our study evaluating the driving abilities of people with schizophrenia, we conducted an exploratory assessment of the primary factors associated with three essential driving techniques required for preventing hazards and accidents (namely, brake response control, steering wheel operation, and SDLP). The variables considered were studied in the context of cognitive functions, cerebral blood flow measured during neuropsychological evaluations, psychiatric manifestations, driving experience, and medication dosage. The findings indicated that cerebral blood flow and TMT-A were the predominant contributors to brake response control, and steering wheel were linked to WMS-R, driving experience, and depression.

This study showed that the cerebral blood flow in the frontal lobe during the administration of neuropsychological tests was associated with brake reaction time. The

frontal lobe is an important region of the brain responsible for judgment; therefore, evaluation of cerebral blood flow in the prefrontal cortex during administration of neuropsychological tests may make a very important contribution to evaluating whether a person can make an appropriate decision to brake in response to a stimulus. Overall, relevant research has shown that reduced frontal lobe activation during driving may lead to an increased risk of collision. Hazard perception is associated with the lateral occipital cortex and right prefrontal cortex (Hirth et al., 2007), and a link between cognitive activity and prefrontal cortex activity in making decisions in dangerous situations has been reported. (Manoach et al., 2003) In the present study, the cognitive function measured was working memory, and working memory deficits in individuals with schizophrenia have been associated with frontal lobe dysfunction (Kumar et al., 2021). Therefore, reduced cerebral blood flow during a working memory task may indicate a driving-related weakness in frontal lobe function. This suggests that the evaluation of frontal lobe function through desk-based assessments can provide an objective prediction of potential collision risk, including reductions in braking speed. Regarding brake reaction speed, visual processing speed assessed using TMT-A correlated well with brake reaction control. Several previous studies on diseases with cognitive impairment have reported that information processing speed based on visual

attention is correlated with behavioral control tasks related to braking, such as reacting to traffic lights, pedestrians, and steering wheel operation task (Aksan et al., 2015; Richardson et al., 2003). The greater the ability to more quickly and accurately make sense of a wider range of visual information assessable on the TMT, the more likely one may tend to have higher automotive skills that rely primarily on visual cognitive–motor output. It is very significant that we were able to show that it is possible to evaluate a brake response task using TMT people with schizophrenia.

Examination of steering operational capabilities revealed that the primary factors identified were visual memory, driving experience, and depression. Considering the results of Analysis 2, driving experience not only molds steering proficiency but also indicates a tendency where augmented driving exposure may elevate the capacity to circumvent accidents. Abilities including steering maneuvers, foreseeing hazards, and evaluating traffic scenarios seem to necessitate hands-on driving experience. There is a credible notion that those who have more driving experience possess an expanded horizon for hazard anticipation. Drivers with Alzheimer's who manifested cognitive deficits exhibited diverse approaches in real-world steering and hazard anticipation according to their driving history, similar to those with schizophrenia (Borowsky et al., 2013; Piersma et al., 2016). For people with schizophrenia, augmenting their driving

exposure might refine their steering strategies and risk discernment. Since the factor that contributed most to steering wheel operation was visual memory, emphasizes on the importance of people with schizophrenia with steering proficiency may be strongly be related to learning ability and learning results.

Regarding schizophrenia symptoms, depression was the sole symptom identified in the model of multiple regression analysis. Intriguingly, the data showed that escalated depressive states paralleled enhanced steering competencies. A recent study on people with schizophrenia indicated that those with subdued self-perceptions and amplified depressive manifestations often displayed superior actual capabilities (Harvey, 2017). Those with intensified depressive states might be more proficient in objectively discerning their environment, perhaps underrepresenting their true skills—a pattern that could also resonate with their driving aptitudes. In addition, collation between disorganized symptoms and steering tactics was observed. Probably, because, disorganized symptoms include the cognitive dysfunction aspect such as attentional deficit (Fountoulakis et al., 2019). More contemporary research on driving-related cognitive and psychomotor attributes flagged disorganized symptoms as the sole symptomatic linkage (Biedermann, 2022).

Furthermore, this study revealed executive functionalities as pivotal elements associated

with the prevention of accidents. The executive functions were considered to be the basic cognitive functions for anticipating and advance planning as well as for responding to unexpected challenges (DiamondAdele, 201003). In this study, the task was to drive while anticipating hazards and avoiding collisions during driving in urban areas. In addition, we used the ZMT to hypothesize that among executive functions, the ability to predict in advance might be related to the ability to predict danger. The results met our expectations, i.e., low planning ability may lead to an inability to anticipate potential hazards in response to cue stimuli for potential collisions, which subsequently may lead to collisions occurring more easily. According to previous studies, this tendency is also true for healthy adults, with Domínguez et al. (2017) reporting that individuals with lower executive function are more likely to engage in riskier driving than healthy individuals. In a study on people with mild dementia, errors in a maze task similar to a ZMT that assessed planning were associated with real-world driving collision rates (Ott et al., 2013). Among executive functions, tasks that evaluate planning may affect the prediction of danger and may be related to collision rates.

In addition to cognitive functions, the present study found that brake reaction time showed significant differences between the collision and noncollision groups. Naturally, the probability of avoiding a collision increases if the driver can quickly apply the

brakes after detecting danger. According to a study on people with dementia driving a car, the ability to react quickly to stimuli still seems to predict success or failure in a real-world driving test; thus, evaluating brake reaction time may be important for assessing safe driving in people with schizophrenia (Piersma et al., 2016).

In contrast, SDLP was not correlated with any of the variables; therefore, SDLP may not be explained by the cognitive functions shown in this study. In opposition to the prevalent assumption that symptoms like tremors, linked to the extrapyramidal system, could negatively impact SDLP, there was no discernible correlation with medication dosage. One plausible reason might be the predominant use of atypical antipsychotic drugs among the participants. These atypical drugs tend to have a reduced propensity to induce extrapyramidal symptoms, potentially accounting for the absent link between driving proficiency and doses when converted to chlorpromazine equivalents.

This study had several limitations. This study is one of the few evaluating driving in individuals with schizophrenia. Considering that correcting the p-value would lead to the risk of type II error (false negatives), we chose not to apply corrections (Rothman., 1990). Additionally, this study primarily focused on those exhibiting stable symptoms, which might account for the absence of observed links between driving aptitudes and specific symptom intensities. Including adaptation of multiple comparisons corrections,

further studies on more number of patients and those examining changes in symptoms and driving competencies using longitudinal methodologies are required.

Moreover, this study focused on actual drivers to maintain uniformity in the baseline understanding and education about driving, encompassing vehicular operations and traffic regulations. This necessitates prudence in extrapolating the results. In terms of evaluating and forecasting the driving capacities of patients with schizophrenia, an imperative avenue for exploration is discerning if comparable patterns manifest among individuals lacking a driving license or those having one but abstaining from driving.

Lastly, this study did not compare patients with schizophrenia with healthy subjects for the following reasons. Subjecting healthy individuals to neuropsychological evaluation tests may obscure genuine correlations because of ceiling effects. (Strauss et al., 2006) For future research development, it is necessary to use driving assessment tools to assess healthy individuals. An exhaustive inquiry is required to identify the driving assessment.

5. CONCLUSIONS

In this study, factors associated with the foundational driving abilities of people with schizophrenia were discerned through multivariate regression analysis by examining

cognitive function, symptoms, neural activity, driving experience, and medication dosage. Assessment of processing speed may be particularly important for the evaluation of basic skills for safe driving. Interestingly, brake control was also associated with cerebral blood flow during the visual working memory task. This result indicates that brain activity in the frontal lobe during a desk-based task may be useful for driving evaluation. Furthermore, collision risk factors were analyzed in this study using a hazard prediction task during urban driving. Low planning, poor driving experience, and slow braking response were identified as the collision factors. The ability of individuals with schizophrenia to anticipate danger and react quickly to avoid collisions may depend on their capacity for proactive planning, rapid braking, and experience. This study could provide data for standardizing driving assessments to assist individuals with schizophrenia to drive safely in the real world.

Acknowledgements
We thank Dr. Shinya Sakai for instruction regarding the use of DS.

Funding
This work was supported by the JSPS KAKENHI (21K21103).

Competing interests
The authors declare no conflicts of interest in association with the present study.

Author contributions

Hiroki Okada: conceptualization, writing original draft, formal analysis, and data interpretation; Takafumi Morimoto and Nozomu Ikeda: conceptualization and supervision.

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Figure Legends

Figure 1. (a) Arrangement of CW-fNIRS probes and channels (CH1–16) (b) Photos of the Honda DS usage.

(a) The spacing between the optodes was 3 cm, and the array of the lower probes measuring channels 3, 9, and 15 was placed along the F7–Fpz–F8 line of the international 10–20 system, covering BA46 (right), BA10, and BA46 (left) (Okamoto et al., 2004). fNIRS: functional near-infrared spectroscopy

(b) The cockpit is equipped with a motion-based unit with 6 degrees of freedom, allowing the driver to experience movements similar to those of a real car. It can also create a realistic acoustic environment with wind noise, engine noise, and other relevant features that create a setting extremely close to driving in a real environment.

Figure 2. The working memory task is shown

The participants had 1.5 seconds to memorize the stimulus location (red square), held it for 7 seconds, and then pressed a button to answer whether the stimulus location matched or did not match within 1.5 seconds.

Figure 3. Hazardous situations in urban driving hazard prediction tasks

The hazardous situations were i) predicting against the blind spot of an oncoming right-turning vehicle in an intersection; ii) predicting against the blind spot of a stopped

vehicle; and iii) predicting the behavior of an oncoming vehicle at an intersection with poor visibility. Cars are present in the blind spots in (a) and (b), and children are present in (c).

Tables

Table 1. Demographics and Clinical Characteristics (N = 42)

Variable	Mean ± SD (MD), or (%)
Age	42.7 ± 7.8 (44)
Male, %	29 (69)
Education (years)	13.9 ± 2.1 (14)
Duration of Illness (years)	19.5 ± 7.4 (21)
Antipsychotic Medication Dose (mg)	496 ± 221 (402.5)
Parking Tickets (number)	.14 ± .35 (0)
Accidents (times)	.27 ± .5 (19)
Driving Experience (years)	14 ± 8.8 (14)
Trail-Making Test A	43.6 ± 13.1 (44)
Trail-Making Test B	77.3 ± 27.6 (74.8)
Wechsler Memory Test–Revised (Visual Memory)	54.3 ± 15.5 (56)
Zoo Map Tests	9.7 ± 3.9 (10)
PANSS Positive [a]	6.9 ± 3.8 (6)
PANSS Negative [b]	11.7 ± 3.8 (10.5)
PANSS Disorganized [c]	4.6 ± 1.9 (4)
PANSS Excited [d]	4.8 ± 1.9 (4)
PANSS Depression [e]	4.8 ± 2 (4)
fNIRS OxyHb (m [mol/L] mm)	.62 ± .07 (.62)

fNIRS = functional near-infrared spectroscopy; oxy-Hb = oxy-hemoglobin; PANSS = Positive and Negative Syndrome Scale; SDLP = standard deviation of lateral position.

a) PANSS Positive: delusions, hallucinations, grandiosity, and unusual thought; b) PANSS Negative: blunted affect, emotional withdrawal, poor rapport, passive/apathetic social, and lack of spontaneity motor retardation; c) PANSS Disorganized: conceptual, difficulty in abstraction withdrawal, and poor attention; d) PANSS Excited: guilt feelings, tension, and motor retardation.

Table 2. Correlations Among Simulated Driving Performance, Demographics and Clinical Characteristics (N = 42)

Variable	50-km Braking reaction time (r)	Curve-driving steering wheel stability (r)	100 km SDLP (r)
Antipsychotic Medication Dose (mg)	–.059	–.059	.224
Driving Experience (years)	–.182	**–.294**†	–.113
Trail-Making Test A	**.393****	**.308***	–.053
Trail-Making Test B	**.330***	.179	.089
Wechsler Memory Test–Revised (Visual Memory)	–.119	**–.371***	–.080
Zoo Map Tests	–.177	**–.296**†	–.262
PANSS Positive [a]	.053	.054	.213
PANSS Negative [b]	.093	–.136	–.220
PANSS Disorganized [c]	.186	**.349***	.018
PANSS Excited [d]	**.295**†	.032	–.087
PANSS Depression [e]	.114	**–.289**†	–.119
fNIRS OxyHb (m [mol/L] mm)	**–.396****	–.084	–.223

†p<.10: *p<.05: **p<.01

fNIRS = functional near-infrared spectroscopy; oxy-Hb = oxy-hemoglobin; PANSS = Positive and Negative Syndrome Scale; SDLP = standard deviation of lateral position.

a) PANSS Positive: delusions, hallucinations, grandiosity, and unusual thought; b) PANSS Negative: blunted affect, emotional withdrawal, poor rapport, passive/apathetic social, and lack of spontaneity motor retardation; c) PANSS Disorganized: conceptual, difficulty in abstraction withdrawal, and poor attention; d) PANSS Excited: guilt feelings, tension, and motor retardation.

Table 3 Multiple regression analysis of basic driving skills: identifying the best contributing factors and models

Model/Step	Variable	β	p	95% CI	R^2_{Adj}	F
Braking reaction time						
Step 1	fNIRS OxyHb	-.396	.009	-1.081 ~ -.162	.136	7.458
Step 2[a)]	fNIRS OxyHb	-.382	.007	-1.025 ~ -.175	.265	8.390
	TMT-A	.379	.007	.001 ~ -.003		
Curve-driving steering wheel stability						
Step 1	WMS-R	-.371	.016	-.003~ -.000	.116	6.380
Step 2	WMS-R	-.374	.011	-.003~ -.000	.187	5.709
	Driving Experience	-.298	.041	-.004~ -.000		
Step 3[b)]	WMS-R	-.370	.000	-.002~ -.000	.259	5.771
	Driving Experience	-.354	.014	-.004~ -.000		
	PANSS Depression	-.302	.035	-.018~ -.000		

a) Variables removed TMT-B p=.299; PANSS Excited p=.081

b) Variables removed TMT-A p=.210; ZMT p=.259; PANSS Disorganized p=.067

fNIRS = functional near-infrared spectroscopy; oxy-Hb = oxy-hemoglobin; TMT= Trail-Making Test; WMS-R=Wechsler Memory Test–Revised (Visual Memory); PANSS = Positive and Negative Syndrome Scale

Table 4. A comparison between the collision group and the noncollision group: differences in cognitive function and symptoms, cerebral blood flow, and driving experience

Variable	Collisions: Mean ± SD (MD)or(%) (N = 16)	Noncollision: Mean ± SD (MD)or (%) (N = 26)	Statistics (Z)	p
Age	42 ± 9.6 (42)	43.3 ± 6.8 (45.5)	-1.118	.237
Male, %※	11 (65)	18 (67)	—	.562
Education (years)	13.3 ± 1.3 (14)	14.8 ± 2.5 (14)	-.234	.813
Duration of Illness (years)	19.3 ± 8.1 (19)	19.7 ± 7.1 (22)	.730	.465
Antipsychotic Medication Dose (mg)	525 ± 177 (550)	478 ± 245.9 (400)	-1.217	.224
Parking Tickets (number)	.19 ± .43 (0)	.38 ± .57 (0)	-.612	.522
Accidents (number)	.13 ± .34 (0)	.38 ± .57 (0)	-.1.529	.111
Driving Experience (years)	9.4 ± 7.7 (7.5)	15.3.4 ± 8.7 (15)	–2.325	**.020***
Trail-Making Test A	46.1 ± 7.4 (45.6)	42.1 ± 15.6 (39.1)	–1.348	.178
Trail-Making Test B	89.6 ± 38.7 (78.2)	69.8 ± 27.2 (74.3)	–1.451	.147
Wechsler Memory Test–Revised (Visual Memory)	48.9 ± 15 (52)	57.9 ± 15.1 (62.5)	–1.660	.097
Zoo Map Tests	7.8 ± 4 (8)	10.9 ± 3.4 (10)	–2.014	**.044***
PANSS Positive [a]	7.2 ± 2.8 (7)	6.8 ± 4.4 (6)	–1.162	.244
PANSS Negative [b]	12.7 ± 4.5 (12.5)	11.1 ± 3.3 (9.5)	–1.162	.245
PANSS Disorganized [c]	5.1 ± 2.5 (4.5)	4.3 ± 1.4 (4)	–.539	.590
PANSS Excited [d]	5.3 ± 2.2 (4)	4.5 ± 1.7 (4)	–1.312.	.810

PANSS Depression [e]	4.9 ± 2.2 (4.5)	4.8 ± 1.9 (4)	–.241	.189
fNIRS OxyHb (m [mol/L] mm)	.006 ± .062 (006)	.006 ± .028 (004)	–.155	.876
100-km Braking for Car That Pulls Out (r)	.652 ± .076 (.65)	.598 ± .058 (586)	–2.035	**.042***
Steering Angle on Car (r)	.274 ± .06 (.28)	.248 ± .06 (.248)	–1.425	.154
100 km SDLP	.020 ± .001 (.02)	.019 ± .003 (.019)	–1.037	.300

※ = $\chi 2$ test; ※= weekly average/month. *<.05: **<.01

fNIRS = functional near-infrared spectroscopy; oxy-Hb = oxy-hemoglobin; PANSS = Positive and Negative Syndrome Scale; SDLP = standard deviation of lateral position.

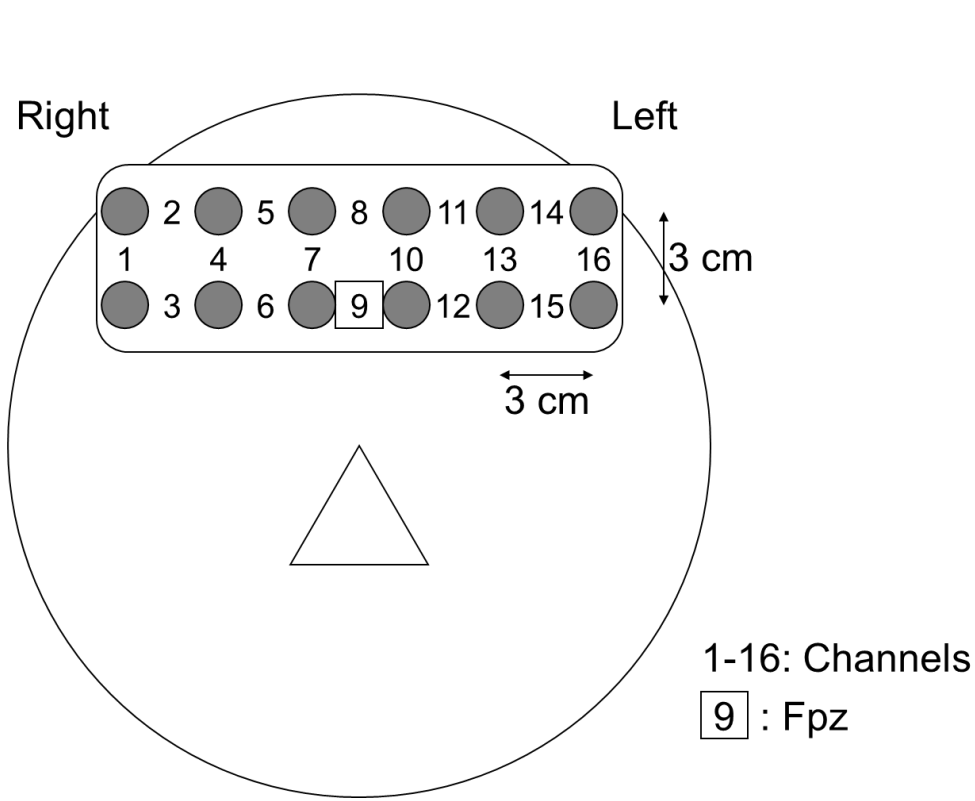
a) PANSS Positive: delusions, hallucinations, grandiosity, and unusual thought; b) PANSS Negative: blunted affect, emotional withdrawal, poor rapport, passive/apathetic social, and lack of spontaneity motor retardation; c) PANSS Disorganized: conceptual, difficulty in abstraction withdrawal, and poor attention; d) PANSS Excited: guilt feelings, tension, and motor retardation.

Table 5 Discriminant score and standardization discrimination coefficient: comparison between the collision group (N = 16) and the noncollision group (N = 26)

Eigenvalue=0.478	variance=100	Canonical function=0.569
Wilks's λ=0.677, p=.002		
Standardization discrimination coefficient		
Zoo Map Tests	.655	
Driving Experience (years)	.578	
Braking reaction time	-.540	

Table 6 Discrimination prediction accuracy: comparison between the collision group (N = 16) and the noncollision group (N = 26)

	Predicted group membership		
Original classification	Collision (%)	Noncollision (%)	Total (%)
Collision (%)	12 (80.8)	4 (19.2)	16 (100)
Noncollision (%)	5 (31.3)	21 (68.8)	26 (100)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2
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1-16: Channels
9 : Fpz

Figure 1

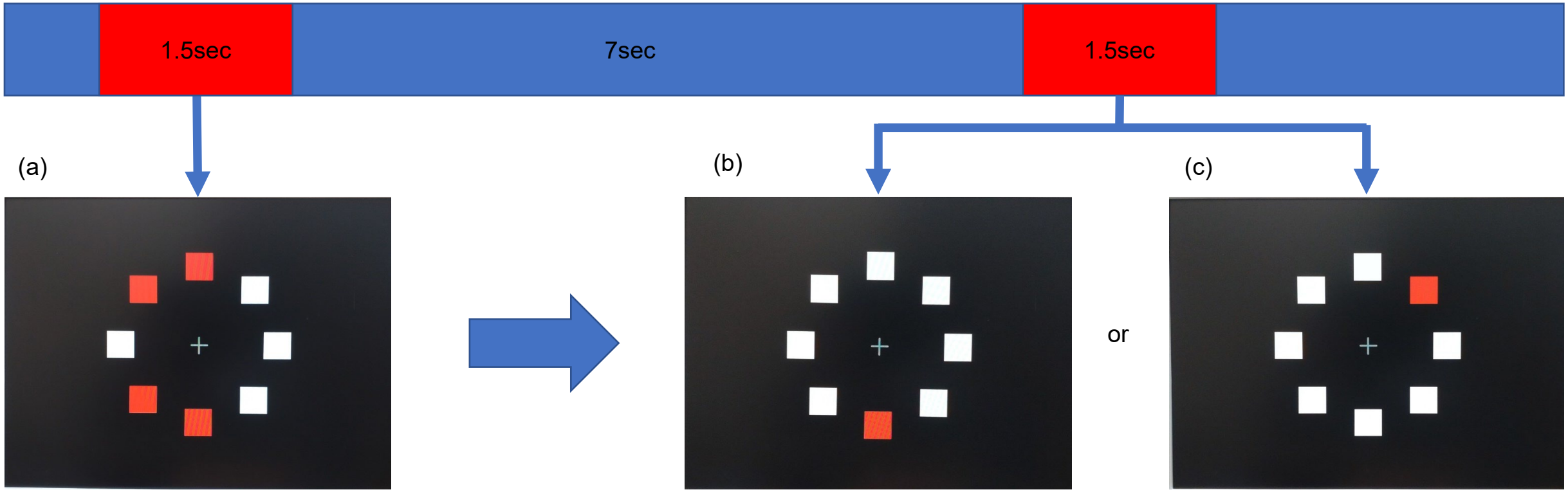
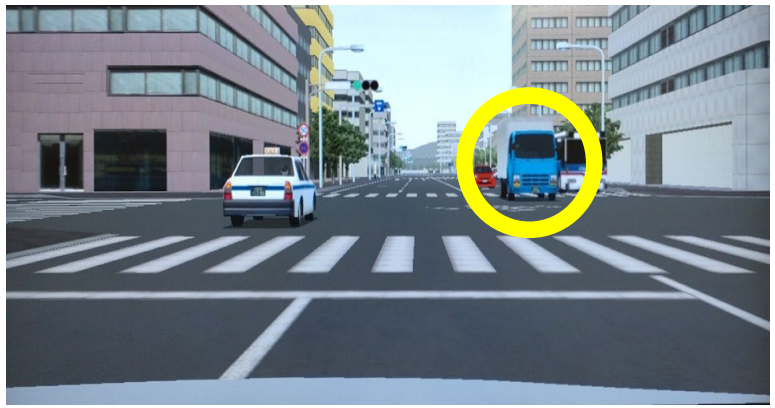


Figure 2

(a)



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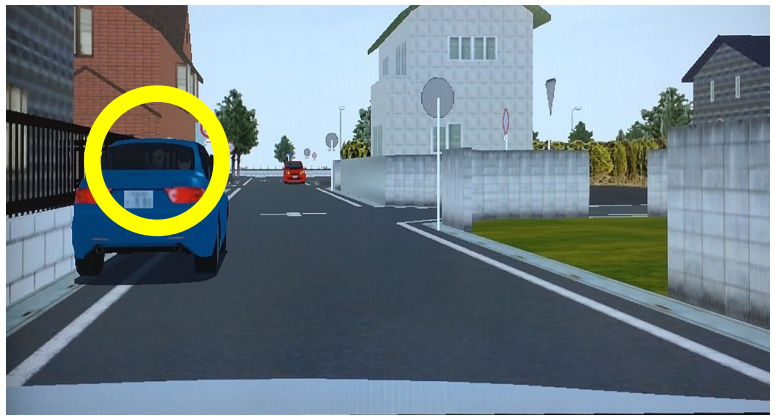

(c)

Figure 3