# Driving Performance and Its Correlation with Neuropsychological Tests in Senior Drivers with Cognitive Impairment in Japan

# （日本の認知障害のある高齢ドライバーにおける運転技能と神経心理学的検査との相関）

彭舟媛

PENG ZHOUYUAN

## INTRODUCTION

Dementia usually results in the deterioration of a wide range of cognitive functions such as memory, orientation, visual-spatial abilities, attention, judgement, decision-making, etc. [1], which overlap with the multiple cognitive domains involved in driving. Indeed, prior literature [2-4] has revealed that dementia or cognitive decline compromises the complex task of driving at multiple levels [5-7]. Additionally, accumulated evidence [8, 9] shows that drivers with dementia or cognitive impairment are more likely to be involved in accidents. While some patients in the early stages of dementia may be able to drive safely [10-12], the progressive nature of the disease implies that the cognitive functions necessary for safe driving would gradually deteriorate and eventually compel the patients to stop driving.

With the rapid aging of the population, the problem of dementia patients as drivers has increasingly emerged globally, including in Japan [13]. In Japan, automobile accidents caused by drivers aged 65 or above have increased since the 1990s [14]. Additionally, the driving license holding rate of seniors has also been increasing, with over 5.82 million seniors aged 75 years or more holding a driving license as at end-2019 [15], indicating that one of every three seniors aged 75 years or more holds a driver's license. In such a situation, Japanese researchers have been focusing on the driving problem of senior drivers with cognitive impairment [16-18], while the government has amended the Road Traffic Act several times in recent years to address this issue. According to the latest amendment implemented in March 2017, when senior drivers aged 75 or above apply for renewal of their driving licenses or commit some specified traffic violations, it is obligatory for them to undergo the Cognitive Impairment Screening Test for Senior Drivers (CISTSD). The CISTSD consists of temporal orientation tests, cued recall tests, and the clock drawing test (CDT). Based on the total score of the CISTSD, the cognitive function of the examinee is categorized as "impaired (the first category)," "slightly impaired (the second category)," or "unimpaired (the third category) [19]." As per the Road Traffic Act, it is mandatory for senior drivers to undergo a formal evaluation for dementia, if they are placed in the first category. Moreover, "dementia" has been specified legislatively as an independent reason for driving license revocation.

Worldwide, there is a consensus that the evaluation of senior drivers' fitness for driving should not be based solely on the medical diagnosis of dementia, but on the individual's actual driving ability [13, 20]. However, this complicated task has posed considerable challenges to health professionals, policy makers, and researchers. Many researchers have been trying to assess the driving ability of senior drivers with cognitive impairment using varied methods, including neuropsychological tests [21], on-road tests [22], off-road driving simulation assessments [23], caregivers' interview [24], naturalistic driving [25], investigation of neuroimaging data [26], etc.

Given that neuropsychological tests, as office-based tools, are easy to administer and undergo, they have been proposed as good methods to predict driving ability. Individual neuropsychological tests were broadly categorized into several cognitive domains, such as global cognition, executive function, attention and concentration, visuospatial function, memory and others [27, 28]. In fact, for each cognitive domain, there is a large variety of measures, approximately 10~20 for each, including a large body of subtests and informal tests. As such, different composite cognitive batteries [11, 13, 29] contained considerably varied measures, and so did the driving performance assessment. Typically, driving outcome was a dichotomous variable developed from aggregating the results of multiple driving ability measures. As a result, variability and inconsistencies have persisted regarding the relationship between scores on the individual neuropsychological tests, tests of a single cognitive domain, or the composite batteries and driving performance. In this study, we chose standard neuropsychological tests of global cognitive function, executive function and attention, visuospatial ability, and episodic memory, all of which are used extensively worldwide.

Notably, given that individuals with different dementia etiology or severity may have different difficulties in executing driving maneuvers [30], it is difficult to find a general pattern of cognitive impairment that correlates with driving ability. This may partly explain why there is still no valid, reliable, and widely accepted composite cognitive battery available for the assessment of driving fitness for all senior drivers with cognitive impairment. Therefore, to determine the one-to-one relationship between the specific driving maneuvers and the specific neuropsychological tests may be a key to the current dilemma. There have been a few studies [31, 32] reporting the correlations between certain neuropsychological tests and certain driving maneuvers. Typically, they have not investigated all the domains of driving behaviors, but focused only on certain situations, such as rear-end collision avoidance [31], and route-following and landmark/sign identification [32]. In this study, to obtain a reliable panoramic view of participants' driving performance, we employed driving simulator tests that detect all domains of driving, including Reaction, Starting and stopping, Signaling, Safety check, Positioning, Speeding, and Overall (wayfinding and accidents). We further explored the correlations between each specific driving maneuver and each standard neuropsychological test.

Thus, the first goal of this study was to investigate which domains of driving maneuvers are impaired in senior drivers with cognitive impairment, by conducting driving simulator tests. Thereafter, we aimed to identify which specific neuropsychological test can significantly reflect a certain driving error. Additionally, we were interested in identifying the difference of cognitive functions and demographic characteristics of senior drivers who continue driving, vis-a-vis those who retired from driving. We hypothesized that the current drivers have better cognitive functions than the retired drivers, but have difficulties in some domains of driving maneuvers, and that different neuropsychological factors serve to predict of different specific driving errors. In conclusion, we aimed to pave the way for more specific guidelines addressing the issue of assessment of driving ability among senior drivers with cognitive impairment in a clinical context.

## METHODS

Ethical approval was granted by the Ethics Committee of Kyoto University Hospital (R1243). Oral and written informed consent was obtained from participants and their caregivers.

### *Participants:*

Subjects who visited the outpatient neurology clinic in Kyoto University Hospital from July 2018 to December 2019 for cognitive complaints or cognitive concerns expressed by their family caregivers were investigated. The eligibility criteria were as follows: aged 60 years or more, having symptoms of cognitive decline objectively or subjectively, and having driving experience, including participants who had already returned their driving licenses and those with a valid driving license. Patients with Alzheimer's disease (AD) or mild cognitive impairment (MCI) were diagnosed by a neurologist, based on the National Institute on Aging-Alzheimer's Association workgroup (NIA-AA) diagnostic criteria, while subjective cognitive decline (SCD) was defined as self-experienced decline in cognitive functions, especially memory, without formal deficits in neuropsychological testing [33]. Participants with comorbidities that might influence driving performance (e.g. history of stroke, Parkinson's disease) and who seldom drove, were excluded from this study.

### *Procedure:*

The participants or their caregivers were asked to complete a questionnaire, which included questions on both the demographic and driving-related characteristics of the participants since the onset of their cognitive problems. All the participants were administered neuropsychological tests by a professional clinical psychologist. However, some senior participants refused to take certain neuropsychological tests due to fatigue; therefore, there are some corresponding missing values. None of the retired drivers in the sample expressed a desire to resume driving or willingness to undergo the driving simulator tests. Of the current drivers, 21 participated in the driving simulator tests. All them completed reaction tests (both simple and complex), but five of them failed to complete the driving test because of simulator sickness.

***Measures:***

**Neuropsychological tests**

The mini-mental state examination (MMSE) is a brief clinical test used for screening dementia patients, with scores ranging from 0 to 30, with lower scores indicating greater cognitive impairment. Although the MMSE alone was perceived to be insufficient for use as an indicator of driving outcomes [10, 28, 34], many studies have provided evidence that it should be used to make the decision to refer senior drivers for a driving evaluation or report them to the respective authorities [20, 35, 36]. The current study included it as a measure of global cognitive functioning and further investigated the correlation between the sub-scores of MMSE and driving parameters.

The trail making test (TMT) [37] is a simple pencil-and-paper task that includes two subtests. Administering the TMT-A requires participants to draw lines to consecutively interconnect 25 numbered circles distributed randomly on a sheet of paper. The TMT-B requires participants to interconnect consecutive numbers and hiragana (a Japanese syllabary) characters, alternating between the two sequences (i.e., number-hiragana-number-hiragana…). Both the subtests measure visual scanning, motor processing speed and attention. The TMT-B additionally tests for divided attention and cognitive flexibility, which play an especially important part in adapting to everchanging traffic situations. The standard administration allows for a maximum time limit of 100 seconds for TMT-A and 300 seconds for TMT-B. However, Russell [38] observed that more than one-third of the patients with neurological disorders exceeded the time limits. Thus, there was no time limit in the study; accordingly, we used the maximum time score obtained from our sample as the score for the participants who failed to complete it. The TMT has been previously reported to be a useful assessment to predict fitness for driving [20, 27]. Moreover, some investigators have proposed the different application strategies of TMT-A and TMT-B [21, 39].

The block design test (BDT) is a subtest of the Wechsler Adult Intelligence Scale (WAIS). It assesses an individual's ability to understand complex visual information. The participants were required to rearrange blocks with various color patterns on different sides to match them to a given pattern. The scores range from 0 to 66 based on accuracy and speed, a higher score indicating a higher level of spatial visualization ability and motor skill. A previous study [4] found that visuospatial construction assessed with the BDT predicted performance for both safety errors and traffic sign identification.

The CDT [40] is a widely used cognitive screening instrument. The participants were instructed to draw the face of a clock and put the numbers of the dial on it, with a long arm and a short arm depicting the time of 10 minutes past 11. To draw the clock, participants must be able to follow directions and visualize the proper orientation of an object. In contrast to the MMSE, this test is unaffected by the participants' level of education [41, 42]. The 10-point Rouleau's scoring system [43] was used in the study, a higher score indicating better cognitive function. CDT has been included in many national medical guidelines for assessing a patient's fitness to drive [13].

The Alzheimer's disease assessment scale–cognitive subscale (ADAS-Cog) [44] assesses the severity of cognitive dysfunction in Alzheimer's disease. It includes 11 tasks, and the scores range from 0 to 70, with higher scores indicating worse cognitive impairment. In most countries, revocation of driving license of senior drivers is based not solely on the diagnosis of dementia, but on its severity [13], which can be evaluated by this test.

Logical memory (LM) I & II [45] are subtests of the revised Wechsler Memory Scale (WMS-R) [46]. It is an episodic memory measure of immediate recall and 30-min delayed recall of two stories A and B. Given that the seniors cannot tolerate prolonged testing, only episode A has been employed in the study. The scores range from 0 to 25 for both LM I and II, a higher score indicating better episodic memory. Episodic memory impairment, one of the earliest and most representative symptoms of AD, may impede driving ability at the strategic level, such as in wayfinding.

## Driving Simulator Tests

For driving simulator tests, we used Honda Safety Navi (Honda Motor Co., Tokyo, Japan; Supplementary Figure 1), a simulator consisting of a steering wheel, a blinker lever, an accelerator pedal, a brake pedal, and three 21.5-inch computer displays that afford the participants a view of the road from the front and sides. However, it is not equipped with a gearbox and clutch, because of the pervasive use of automatic transmission cars in Japan. The speedometer, side mirrors and the rear-view mirror are shown on the screens, and the simulated driving sound is played to mimic a real-world scenario. For the evaluation of driving ability, a special software, the Honda driving ability evaluation supportive software (Honda Motor Co., Tokyo, Japan), was installed. With this software, we administered two types of tests: two reaction tests (simple and complex) and one driving test to reflect real-world driving.

The reaction tests were used to measure a participant's reaction time to stimuli while driving and consisted of two subtests: simple and complex reaction tests. The reaction tests are set on a one-way road in a rural scenario. The researcher elaborately explained the details of each subtest, so that the participants had a clear idea. The participants were required to follow a car in front and rapidly operate the accelerator and brake pedals according to the color of the rear lights of the car in front (details in Supplementary Table 1). Before the formal test, there were five and six practice stimuli for the simple and complex reaction tests, respectively. The mean of reaction time (RT) and deviation of reaction time (dRT) were automatically recorded both for the simple (35 stimuli) and complex (50 stimuli) reaction tests. The number of erroneous reactions (eR) in the complex reaction test was also recorded. The software then compared each evaluation item to that of the existing data of generally healthy people of the same age and reported results with a 5-level evaluation ranking (Poor, Below Average, Average, Good, and Excellent) for each participant.

The driving test was set in an urban environment during daytime, to measure a participant's driving errors in 6 domains: Starting and stopping, Signaling, Safety check, Positioning, Speeding, and Overall. The researcher explained the overall setting of the test and told the participants that they needed to complete 12 tasks and reach the given destination by correctly following the audio navigation (turning left/right, changing lanes, etc.) and signboards. The 12 tasks and corresponding traffic scenarios are described in Supplementary Table 1. The participants were instructed to drive as usual and obey traffic rules (traffic lights and posted speed limitations, etc.). Before the formal test, participants were allowed a practice drive to help them get a general idea of the test and familiarize themselves with operating the simulator. The simulator software automatically recorded and counted 18 objective parameters of driving errors and categorized them into the 6 domains of driving maneuvers (details in Table 4). Similarly, the software compared the result of each domain to that of generally healthy people of the same age and reported evaluation rankings that were displayed in a radar chart (Supplementary Figure 2) to show the participants' driving performance integrally.

The driving simulator tests lasted approximately 30 minutes, each test followed by a short break. Participants were instructed to report at any time if they felt unwell (dizziness or nausea), and could abort the test. After the test, a printed report of their driving performance was provided to them upon request (Supplementary Figure 2).

***Statistical analyses:***

Analyses were performed using IBM® SPSS® Statistics version 23. The chi-square test or Fisher exact test was used to compare all the demographic（except "age"）and driving-related characteristics according to the status of the driving licenses. The independent samples t-test or

Mann-Whitney *U* test was conducted to compare the scores of neuropsychological tests of current/retired groups. Analysis of covariance (ANCOVA) was conducted to adjust for age and gender, as the two groups differed significantly in these variables. In addition, the Cohen's d was computed to indicate the effect size. Negligible effects (d < 0.20), small effects (0.20 < d < 0.50), medium effects (0.50 < d < 0.80) and large effects (d > 0.80) were distinguished. ANOVA tests and Post Hoc tests were used to compare the driving performance of participants with different diagnoses. The Pearson correlation coefficient or the Spearman's $\rho$ was used to determine the one-to-one relationship between the specific driving parameters and the scores of specific neuropsychological tests. Regrettably, the number of participants who could ultimately be studied using the driving simulator was too small to apply multivariate regression analysis. All statistical significance tests were two-sided, and an $\alpha$ level of 0.05 was considered statistically significant. It is to be noted that many statistical comparisons were made in this single study simultaneously; hence, it is necessary to consider the fallacy of multiple comparisons when interpreting our results.

## RESULTS

### *Demographic and driving-related characteristics*

Of the 52 participants investigated, five were excluded: one for being under 60, two because of a lack of actual driving experience, and two with comorbidities that might influence driving performance. Eventually, 47 participants were included in the study, ranging in age from 61 to 92, of whom 27 (57.4%) were male. 24 participants had voluntarily returned their driving licenses, whereas 23 still held a valid driving license at the time of the study. The number of participants diagnosed with SCD, MCI, and AD was 5, 19, and 23, respectively.

Table 1 presents the demographic and driving-related characteristics of retired and current drivers. Apart from self-reported traffic accidents, significant differences were found between the two groups in age, gender, diagnosis, driving patterns, driving frequency, and duration of driving experience. The current drivers were statistically younger than the retired ones ($t$ = 3.105 $p$ = 0.003), and a higher proportion of current drivers was male; the opposite pattern held true for retired drivers ($\chi^2$ = 4.996, $p$ = 0.039). Most current drivers had a diagnosis of MCI or SDC, whereas the most frequent diagnosis among the retired drivers was AD. The majority (87.5%) of retired drivers thought that they were unable to drive safely anymore, but three of them had a relatively optimistic assessment of their driving competence and were convinced they could drive safely in certain conditions, such as during the daytime, in favorable weather, around the neighborhood, etc. Of the current drivers, more than half thought they could drive safely unconditionally, whereas only some voluntarily imposed restrictions on their driving behaviors.

Four retired drivers and eight current drivers reported having caused traffic accidents since the onset of cognitive problems, and the accidents were almost all run-off-road collisions without injury.

### *Neuropsychological tests*

As displayed in Table 2, the differences between the retired and current drivers were statistically significant for the scores of all neuropsychological tests, even after the adjustment for gender. However, the scores of ADAS and WMS-LM II were found to be statistically not different between the two groups after adjustment for age. The overwhelming majority of current drivers (82.6%) had an MMSE score higher than 23, with a minimum of 19 and maximum of 27. The MMSE scores of retired drivers were in a larger range, with a minimum of 2 and maximum of 27.

### *Driving performance*

Twenty-one current drivers participated in the reaction tests, aged between 61 and 90 (mean [SD], 76.38 [7.11]), 15 of whom were male. As displayed in Fig.1, more than half of the 21 participants had a below average or poor ranking on the evaluation items both of the simple and complex reaction tests. Table 3 shows the results of the reaction tests of the participants with different diagnoses. There were 4, 14, and 3 participants in the SCD, MCI, and AD groups respectively and the age and gender of the three groups were not significantly different. According to the results of ANOVA, the sim-RT ($p < 0.001$), the sim-dRT ($p = 0.001$), the com-dRT ($p = 0.001$), and the eR ($p = 0.027$) were significantly related to the diagnosis. According to the results of Post Hoc tests, the mean of sim-RT and sim-dRT of the AD group was significantly larger than that of the SCD and MCI groups, but no significant difference was found between the latter two groups. The mean of com-dRT of the 3 groups was significantly different, that of the SCD group being the smallest. The eR of the SCD group was significantly less often than that of the MCI group, but no significant difference was found in other comparisons.

Sixteen current drivers completed the driving test, aged between 64 and 90 (mean [SD], 77.75 [6.77]), 14 of whom were male. Table 4 shows the median of the frequency of 18 driving errors and the evaluation ranking of the 6 domains of driving maneuvers of the 16 participants. Among all the 6 domains of driving maneuvers, Safety check, Positioning, and Speeding of all the 16 participants were evaluated to be above the average level. However, there were 4, 3, and 8 participants with a ranking below the average level on Starting and stopping, Signaling, and Overall, respectively. Pairwise comparisons yielded significant differences between the SCD and MCI groups for “overlooking dangerous vehicles ahead” ($p = 0.039$) and between the AD and

MCI groups for "centerline crossings" ($p = 0.008$), with no significant differences between the three groups for all other driving errors, which may at least partly be due to the small sample size, especially in the SCD (2 participants) and AD groups (3 participants).

***Correlative Analyses***

As shown in Table 5, many neuropsychological factors were found to have significantly moderate to high correlations with the parameters of different domains of driving performance. In general, the parameters of the reaction tests were found to be associated with the scores of MMSE, TMT-A, and TMT-B. With respect to the parameters of driving errors, Spearman's $\rho$ revealed that "sudden braking" had quite a high correlation coefficient with the scores of MMSE ($\rho = -0.707$, $p< 0.01$), BDT ($\rho = -0.560$, $p < 0.05$) and ADAS ($\rho = 0.758$, $p < 0.01$); "Forgetting to use turn signals" was associated with the TMT-B score ($\rho = 0.608$, $p < 0.05$); "Centerline crossings" was moderately correlated with the scores of MMSE ($\rho = -0.582$, $p < 0.05$) and ADAS ($\rho = 0.538$, $p < 0.05$); "Going the wrong way" was moderately correlated with the score of CDT ($\rho = -0.624$, $p < 0.01$). All specific data are listed in Table 5.

## DISCUSSION

Our study found that many senior drivers regulate their driving patterns in a proactive way upon the onset of cognitive problems. In this study population, a little over 50 % of the participants had stopped driving. According to the results of a survey[47] conducted by the National Police Agency (Japan), the top three reasons why senior drivers stopped driving were frailty, families' recommendation, and having read the news of traffic accidents caused by senior divers. Further, a proportion of current drivers had voluntarily restricted their driving behaviors, such as driving only in familiar residential areas and for short distances, driving during the hours of low traffic, etc. The phenomenon of self-imposed restriction on driving behavior was also reported by Kurzthaler et al. [48], who interpreted it as a compensatory strategy. In our sample, younger people, males, and those with longer driving experience were more likely to be current drivers, in the light of demographic and driving-related characteristics. A similar pattern emerged in several previous studies [49-51]. As expected, current drivers performed better in neuropsychological testing than retired ones, which is in agreement with the findings of Vaughan et al. [52].

With respect to driving performance, the participants showed driving errors in the 4 domains in general: Reaction, Starting and Stopping, Signaling, and Overall (wayfinding and accidents), which was detected by the driving simulator tests. Approximately half of the 21 participants displayed slow response to sudden events while driving (see sim-RT and com-RT in Fig. 1). More precisely, the responses of AD patients were slower than the SCD and MCI groups in simple reaction tests; but in the complex situation, there was no difference among the RT of the three groups (Table 3), which is in line with a recent study [53] reporting that drivers with AD showed significantly greater RT than control drivers in simulated driving. In addition, more than half the participants lacked stability of driving operations (see sim-dRT and com-dRT in Fig. 1). Pairwise comparisons indicated that the operation stability of AD patients was significantly the worst in the simple reaction test (see sim-dRT in Table 3). However, in more complex situations, no significant difference was found between the operation stability of the AD and MCI groups, with participants with SCD showing the best operation stability. Moreover, based on the eR results, participants with SCD had misjudgments or incorrect manipulations in complex situations, less often than the MCI group (Table 3).

Based on the results of the 16 subjects who completed the driving test, the most frequent driving errors included traffic lights or stop sign violations, inappropriate use of the indicator, stepping on the accelerator or brakes suddenly, stopping inappropriately, and causing crashes or collisions. Although most of them did not commit speeding violations, the crawling problem might have been hidden, because it was observed that some participants drove at excessively slow speeds in the simulated driving. However, the simulator software used in our study did not measure the average speed of the participants. Economou et al. [53] also pointed out the crawling problem of senior drivers, and interpreted it as a compensatory behavior to cope with the complex simulated traffic. Piersma et al. [11] found that patients with AD drove significantly more slowly than healthy participants, when they were in a hurry or at the intersections. In contrast, Yamin et al. [34] concluded that drivers with AD exceeded the posted speed limit significantly more often in comparison to the controls. These discrepant results may be due to the difficulty of driving tests used in different studies varying a lot, which may have an effect on the speed control. In terms of Positioning and Safety check, all the 16 participants received a ranking equal to or greater than the average (Table 4). However, “Safety check” might be worse than the current result, because the driving error, “inappropriate side safety check,” was not involved in our study.

Our findings suggest that certain individual neuropsychological tests may be good predictors of certain driving maneuvers. Many of the existing studies have elucidated the relationships between neuropsychological tests and integral driving outcome, to predict driving fitness. In contrast, we divided the driving abilities into several domains, and then tried to find the appropriate neuropsychological test which significantly reflects a certain domain of driving abilities. In this respect, the present study is one of the few[54, 55] to examine the correlation between each specific driving behavior and each single neuropsychological test.

Our study provides evidence that the reactivity in driving could be predicted by cognitive tests that contain or emphasize the attention function, such as MMSE, TMT-A, and TMT-B (Table 5). A prior study[55] has drawn a similar conclusion that responses to road hazards were significantly predicted solely by attention in a sample with cognitively healthy senior drivers. Both the scores of MMSE and the subtest of "attention and calculation" exhibited strong negative correlations with the parameters of Reaction, indicating that MMSE would be useful to assess senior drivers' reactivity, and the subtest, "attention and calculation," may be a good alternative, demanding less time. Similarly, the scores of "orientation to time" and "recall" showed significant correlations with dRT or eR, which suggests these as simple and easy ways to evaluate the stability and adaptability of driving operations. In addition, prolongation in TMT-A and TMT-B scores were also proved to be predictors of reacting tardily and unstably. Interestingly, the TMT-B score was also predictive of the operation of giving turn signals (see FUTS in Table 5), which is important for avoiding accidents when making turns or changing lanes. Senior drivers with worse performance in TMT-B test were more likely to fail to indicate turn signals in time or to forget to giving turn signals at all.

The importance of the visuospatial function in explaining operational driving mistakes has been emphasized in many studies. A meta-analysis [27] reported that visuospatial function emerged as one of the significant predictors of driving performance, with relatively high effect size. Yamin et al. [34] proved the association between visual processing and number of crashes, illustrating visual processing being an initial step in crash avoidance. Yi et al. [23] found that impairment in visual attention contributed to an increased risk of crashes. Ergun et al. [31] reported that Rey-Osterreith complex figure test and other visual tests were predictive of premature stopping and abrupt slowing. Similarly, our study found that the frequent and sudden slamming of the brakes was associated with a decrease in visuospatial ability, as detected by BDT (see SB in Table 5). Besides, we found that both the measures of global cognitive functioning (MMSE and ADAS) also serve to predict the driving maneuvers of sudden braking.

Prior studies have provided evidence that the global cognitive status is correlated with the driving behavior of lane control both in on-road driving test[56] and simulated driving tests [11, 34]. In our study, this correlation was further confirmed (see CC in Table 5). Specifically, both the measures of global cognitive functioning used in our study, MMSE and ADAS, revealed similar validity in predicting the driving maneuvers of lane control.

The CDT is included in many studies [57-59] that aimed to identify the best predictive set of tests for pass/fail driving outcome. Nevertheless, there is little evidence linking the CDT to specific driving behaviors. In the study, way-finding, a driving behavior at the strategic level, was found to be predicted by the CDT score (see GWW in Table 5). Although the CDT is included in many national medical guidelines to assess the driving ability of senior drivers, one study [60] demonstrated the limited utility of CDT as a single screening measure in predicting driving performance. Our study confirmed the usefulness of CDT in assessing some specific driving behaviors, especially those at the strategic level.

Unexpectedly, the subtest of MMSE “orientation to time” had a significantly positive correlation with the behavior of driving over the speed limit (see R-DOSL, OS-SL in Table 5). It is plausible that participants with greater temporal orientation skill may have excessive confidence in their driving, resulting in their driving much faster. In addition, it is to be noted that in our sample, no parameter of driving performance was found to be significantly correlated with memory detected by LM. This is compatible with the results of a previous study [48], which found that memory itself did not significantly contribute to the prediction of driving behaviors. Likewise, after adjusting for age, we found that there was no significant difference between the delayed recall of current drivers and retired drivers. In Japan, memory tests (cued recall tests) are used in the CISTSD mentioned in the introduction. This finding questions the validity of employing memory tests to screen the driving ability of senior drivers.

The major limitation of this study is the small sample size that may affect the reliability of our findings. It is important to be cautious when interpreting our results. Consequently, the small sample size limited the statistical analysis. Just 16 participants completing the driving test is insufficient to develop a sophisticated statistical model. The limited sample size was partly due to simulator sickness, which is a common problem reported by many studies. Various countermeasures were adopted to mitigate this effect, including individualizing the accommodation phase [34] and simplifying the simulator scenarios [11, 57]. A further limitation is that the present study used only parameters put out by the software automatically, to assess driving performance. It may be helpful to incorporate an observational assessment [57] in addition to the objective parameters, for a more comprehensive evaluation. Further, the missing values of the neuropsychological tests comprise a shortcoming of the study. In future, a larger sample is warranted to confirm the validity of our findings.

Our results concerning the driving errors of senior drivers with cognitive impairment constitute a useful addition to the literature. We have also updated the current literature on this topic by linking classical office-based neuropsychological tests to specific driving maneuvers. In sum, the unique neuropsychological domain of attention can reflect the reaction in driving; the visuospatial function serves the prediction of the braking operation, the global cognitive function is good at predicting the driving maneuver of positioning, and CDT is correlated with strategic difficulties. To protect the driving privilege of senior drivers and, at the same time, ensure that traffic accidents attributable to them do not increase, an integrant neuropsychological tool that can accurately reflect individuals' driving abilities needs to be developed. This newly gained information provides assistance to the design of assessment batteries specifically tailored to different etiologies. In addition, we can optimize the battery by adjusting it flexibly, depending on personalized driving problems reported by caregivers in clinical practice.

## ACKNOWLEDGMENTS

This study was supported by two research grants from the Takata Foundation (Project No. 203170600011 and 203190600065). The funding sources did not have any specific involvement in this study. We would like to thank Ms. Momoyo Shimosaka, Dr. Masakazu Miyamoto, Ms. Atsuko Kokuryu, and Ms. Noriko Uchida, for their administrative support of collecting the data used in the study.

## CONFLICT OF INTEREST

The authors have no conflict of interest to report.

## REFERENCES

[1] World Health Organization, Dementia, https://www.who.int/en/news-room/fact-sheets/detail/dementia, Last updated September 21, 2020, Accessed on October 29, 2020.

[2] Andrew C, Traynor V, Iverson D (2015) An integrative review: understanding driving retirement decisions for individuals living with a dementia. *J Adv Nurs* **71**, 2728-2740.

[3] Schmidtke K (2018) [Driving ability in mild cognitive impairment and dementia]. *Fortschr Neurol Psychiatr* **86**, 37-42.

[4] Aksan N, Dawson JD, Emerson JL, Yu L, Uc EY, Anderson SW, Rizzo M (2012) Naturalistic Distraction and Driving Safety in Older Drivers. *Human Factors: The Journal of the Human Factors and Ergonomics*

*Society* **55**, 841-853.

[5] Piersma D, de Waard D, Davidse R, Tucha O, Brouwer W (2016) Car drivers with dementia: Different complications due to different etiologies? *Traffic Inj Prev* **17**, 9-23.

[6] Fuermaier ABM, Piersma D, de Waard D, Davidse RJ, de Groot J, Doumen MJA, Bredewoud RA, Claesen R, Lemstra AW, Scheltens P, Vermeeren A, Ponds R, Verhey F, De Deyn PP, Brouwer WH, Tucha O (2019) Driving Difficulties Among Patients with Alzheimer's Disease and Other Neurodegenerative Disorders. *Journal of Alzheimers Disease* **69**, 1019-1030.

[7] Devlin A, McGillivray J, Charlton J, Lowndes G, Etienne V (2012) Investigating driving behaviour of older drivers with mild cognitive impairment using a portable driving simulator. *Accident Analysis & Prevention* **49**, 300-307.

[8] Meuleners LB, Ng J, Chow K, Stevenson M (2016) Motor Vehicle Crashes and Dementia: A Population-Based Study. *J Am Geriatr Soc* **64**, 1039-1045.

[9] Fraade-Blanar LA, Ebel BE, Larson EB, Sears JM, Thompson HJ, Chan KCG, Crane PK (2018) Cognitive Decline and Older Driver Crash Risk. *J Am Geriatr Soc* **66**, 1075-1081.

[10] Fujito R, Kamimura N, Ikeda M, Koyama A, Shimodera S, Morinobu S, Inoue S (2016) Comparing the driving behaviours of individuals with frontotemporal lobar degeneration and those with Alzheimer's disease. *Psychogeriatrics* **16**, 27-33.

[11] Piersma D, Fuermaier AB, de Waard D, Davidse RJ, de Groot J, Doumen MJ, Bredewoud RA, Claesen R, Lemstra AW, Vermeeren A, Ponds R, Verhey F, Brouwer WH, Tucha O (2016) Prediction of Fitness to Drive in Patients with Alzheimer's Dementia. *PLoS One* **11**, e0149566.

[12] Davis RL, Ohman JM (2017) Driving in Early-Stage Alzheimer's Disease: An Integrative Review of the Literature. *Res Gerontol Nurs* **10**, 86-100.

[13] Kim YJ, An H, Kim B, Park YS, Kim KW (2017) An International Comparative Study on Driving Regulations on People with Dementia. *J Alzheimers Dis* **56**, 1007-1014.

[14] Cabinet Office (Japan), White Paper on Traffic Safety in Japan 1997

(Abridged Edition), https://www8.cao.go.jp/koutu/taisaku/h09-haku_e/haku97e0.htm, Last updated June, 1997, Accessed on March 6, 2020.

[15] National Police Agency (Japan), Ryō wa gan'nen-ban unten menkyo tōkei (2019 Driver's License Statistics), https://www.npa.go.jp/publications/statistics/koutsuu/menkyo/r01/r01_main.pdf, Last Updated March 24, 2020, Accessed on April 1, 2020.

[16] Kamimura N, Kakeda K, Kitamura Y, Sanada J, Ikeda M, Inoue S (2005) [Dementia and driving: present status of drivers with dementia and response of their family's care in Japan]. *No To Shinkei* **57**, 409-414.

[17] Kamimura N (2006) [Social aspects of dementia: an overview of the Japanese researches about driving in patients with dementia]. *No To Shinkei* **58**, 463-470.

[18] Ichikawa M, Nakahara S, Inada H (2015) Impact of mandating a driving lesson for older drivers at license renewal in Japan. *Accid Anal Prev* **75**, 55-60.

[19] National Police Agency (Japan), Cognitive Function Test for Senior Drivers, https://www.npa.go.jp/english/bureau/traffic/index.html, Last updated April 1, 2020, Accessed on April 20, 2020.

[20] Cameron DH, Zucchero Sarracini C, Rozmovits L, Naglie G, Herrmann N, Molnar F, Jordan J, Byszewski A, Tang-Wai D, Dow J, Frank C, Henry B, Pimlott N, Seitz D, Vrkljan B, Taylor R, Masellis M, Rapoport MJ (2017) Development of a decision-making tool for reporting drivers with mild dementia and mild cognitive impairment to transportation administrators. *Int Psychogeriatr* **29**, 1551-1563.

[21] Papandonatos GD, Ott BR, Davis JD, Barco PP, Carr DB (2015) Clinical Utility of the Trail-Making Test as a Predictor of Driving Performance in Older Adults. *Journal of the American Geriatrics Society* **63**, 2358-2364.

[22] Hotta R, Makizako H, Doi T, Tsutsumimoto K, Nakakubo S, Makino K, Shimada H (2018) Cognitive function and unsafe driving acts during an on-road test among community-dwelling older adults with cognitive impairments. *Geriatr Gerontol Int* **18**, 847-852.

[23] Yi J, Lee HC-Y, Parsons R, Falkmer T (2015) The Effect of the Global Positioning System on the Driving Performance of People with Mild

Alzheimer's Disease. *Gerontology* **61**, 79-88.

[24] Lee L, Molnar F (2017) Driving and dementia: Efficient approach to driving safety concerns in family practice. *Can Fam Physician* **63**, 27-31.

[25] Roe CM, Stout SH, Rajasekar G, Ances BM, Jones JM, Head D, Benzinger TLS, Williams MM, Davis JD, Ott BR, Warren DK, Babulal GM (2019) A 2.5-Year Longitudinal Assessment of Naturalistic Driving in Preclinical Alzheimer's Disease. *Journal of Alzheimers Disease* **68**, 1625-1633.

[26] Megevand P, Groppe DM, Goldfinger MS, Hwang ST, Kingsley PB, Davidesco I, Mehta AD (2014) Seeing scenes: topographic visual hallucinations evoked by direct electrical stimulation of the parahippocampal place area. *J Neurosci* **34**, 5399-5405.

[27] Hird MA, Egeto P, Fischer CE, Naglie G, Schweizer TA (2016) A Systematic Review and Meta-Analysis of On-Road Simulator and Cognitive Driving Assessment in Alzheimer's Disease and Mild Cognitive Impairment. *J Alzheimers Dis* **53**, 713-729.

[28] Bennett JM, Chekaluk E, Batchelor J (2016) Cognitive Tests and Determining Fitness to Drive in Dementia: A Systematic Review. *J Am Geriatr Soc* **64**, 1904-1917.

[29] Vella K, Lincoln NB (2014) Comparison of assessments of fitness to drive for people with dementia. *Neuropsychol Rehabil* **24**, 770-783.

[30] Piersma D, Fuermaier ABM, De Waard D, Davidse RJ, De Groot J, Doumen MJA, Bredewoud RA, Claesen R, Lemstra AW, Scheltens P, Vermeeren A, Ponds R, Verhey F, De Deyn PP, Brouwer WH, Tucha O (2018) Assessing Fitness to Drive in Patients With Different Types of Dementia. *Alzheimer Dis Assoc Disord* **32**, 70-75.

[31] Uc EY, Rizzo M, Anderson SW, Shi Q, Dawson JD (2006) Unsafe rear-end collision avoidance in Alzheimer's disease. *Journal of the Neurological Sciences* **251**, 35-43.

[32] Aksan N, Anderson SW, Dawson J, Uc E, Rizzo M (2015) Cognitive functioning differentially predicts different dimensions of older drivers' on-road safety. *Accident Analysis and Prevention* **75**, 236-244.

[33] Jessen F, Amariglio RE, van Boxtel M, Breteler M, Ceccaldi M, Chetelat G, Dubois B, Dufouil C, Ellis KA, van der Flier WM, Glodzik L, van

Harten AC, de Leon MJ, McHugh P, Mielke MM, Molinuevo JL, Mosconi L, Osorio RS, Perrotin A, Petersen RC, Rabin LA, Rami L, Reisberg B, Rentz DM, Sachdev PS, de la Sayette V, Saykin AJ, Scheltens P, Shulman MB, Slavin MJ, Sperling RA, Stewart R, Uspenskaya O, Vellas B, Visser PJ, Wagner M, Grp SIW (2014) A conceptual framework for research on subjective cognitive decline in preclinical Alzheimer's disease. *Alzheimers & Dementia* **10**, 844-852.

[34] Yamin S, Stinchcombe A, Gagnon S (2016) Deficits in Attention and Visual Processing but not Global Cognition Predict Simulated Driving Errors in Drivers Diagnosed With Mild Alzheimer's Disease. *Am J Alzheimers Dis Other Demen* **31**, 351-360.

[35] Lovas J, Fereshtehnejad SM, Cermakova P, Lundberg C, Johansson B, Johansson K, Winblad B, Eriksdotter M, Religa D (2016) Assessment and Reporting of Driving Fitness in Patients with Dementia in Clinical Practice: Data from SveDem, the Swedish Dementia Registry. *J Alzheimers Dis* **53**, 631-638.

[36] Adler G, Rottunda S, Dysken M (2005) The older driver with dementia: an updated literature review. *J Safety Res* **36**, 399-407.

[37] Sugimoto S, Okuma O, Koyama T, Sakuma H, Komiyama J, Ozawa I, Murooka O, Nakajo M, Kihashi A (2014) Relationship between a Simplified Version of the Trail Making Test and the Japanese Version of the Trail Making Test. *Rigakuryoho Kagaku* **29**, 357-360.

[38] Russell EW (1980) Tactile Sensation - an All-or-None Effect of Cerebral-Damage. *Journal of Clinical Psychology* **36**, 858-864.

[39] Duncanson H, Hollis AM, O'Connor MG (2018) Errors versus speed on the trail making test: Relevance to driving performance. *Accid Anal Prev* **113**, 125-130.

[40] Agrell B, Dehlin O (1998) The clock-drawing test. *Age and Ageing* **27**, 399-403.

[41] Konagaya Y, Watanabe T, Konagaya M (2012) [Cognitive function screening of community-dwelling elderly people using the clock drawing test -quantitative and qualitative analyses]. *Nihon Ronen Igakkai Zasshi* **49**, 483-490.

[42] de Noronha IFC, Barreto SDS, Ortiz KZ (2018) The influence of

education on performance of adults on the Clock Drawing Test. *Dement Neuropsychol* **12**, 61-67.
[43] Rouleau I, Salmon DP, Butters N, Kennedy C, Mcguire K (1992) Quantitative and Qualitative Analyses of Clock Drawings in Alzheimers and Huntingtons-Disease. *Brain and Cognition* **18**, 70-87.
[44] Numata Y (2018) [Alzheimer's Disease Assessment Scale-Cognitive Subscale Japanese version (ADAS-J cog)]. *Rōnen seishin igaku zasshi* **29**, 1150-1155.
[45] Kawano N, Awata S, Ijuin M, Iwamoto K, Ozaki N (2013) Necessity of normative data on the Japanese version of the Wechsler Memory Scale-Revised Logical Memory subtest for old-old people. *Geriatrics & Gerontology International* **13**, 726-730.
[46] Koike A, Sugishita M (2011) [The Japanese version of the Wechsler Memory Scale--revised]. *Nihon Rinsho* **69 Suppl 8**, 408-412.
[47] National Police Agency (Japan), Ninchi kinō to anzen unten no kankei ni kansuru chōsa kenkyū (Research on the Relationship between Cognitive Functions and Safe Driving), https://www.npa.go.jp/koutsuu/kikaku/koureiunten/menkyoseido-bunkakai/cognitivef/cognitivef_report.pdf, Last updated March, 2019, Accessed on October 31, 2019.
[48] Kurzthaler I, Kemmler G, Defrancesco M, Moser B, Fleischhacker WW, Weiss EM (2017) Executive Dysfunctions Predict Self-Restricted Driving Habits in Elderly People with or without Alzheimer's Dementia. *Pharmacopsychiatry* **50**, 203-210.
[49] Pyun JM, Kang MJ, Kim S, Baek MJ, Wang MJ, Kim S (2018) Driving Cessation and Cognitive Dysfunction in Patients with Mild Cognitive Impairment. *J Clin Med* **7**.
[50] Connors MH, Ames D, Woodward M, Brodaty H (2018) Predictors of Driving Cessation in Dementia: Baseline Characteristics and Trajectories of Disease Progression. *Alzheimer Disease & Associated Disorders* **32**, 57-61.
[51] Feng YR, Meuleners L, Stevenson M, Heyworth J, Murray K, Maher S (2020) Driver Self-Regulation Practices in Older Drivers with and Without Mild Cognitive Impairment. *Clinical Interventions in Aging* **15**,

217-224.

[52] Vaughan L, Hogan PE, Rapp SR, Dugan E, Marottoli RA, Snively BM, Shumaker SA, Sink KM (2015) Driving with Mild Cognitive Impairment or Dementia: Cognitive Test Performance and Proxy Report of Daily Life Function in Older Women. *J Am Geriatr Soc* **63**, 1774-1782.

[53] Economou A, Pavlou D, Beratis I, Andronas N, Papadimitriou E, Papageorgiou SG, Yannis G (2020) Predictors of accidents in people with Mild Cognitive Impairment, mild dementia due to Alzheimer's disease and healthy controls in simulated driving. *International Journal of Geriatric Psychiatry*.

[54] Anstey KJ, Wood J (2011) Chronological Age and Age-Related Cognitive Deficits Are Associated With an Increase in Multiple Types of Driving Errors in Late Life. *Neuropsychology* **25**, 613-621.

[55] Cuenen A, Jongen EMM, Brijs T, Brijs K, Lutin M, Van Vlierden K, Wets G (2016) The relations between specific measures of simulated driving ability and functional ability: New insights for assessment and training programs of older drivers. *Transportation Research Part F-Traffic Psychology and Behaviour* **39**, 65-78.

[56] Wadley VG, Okonkwo O, Crowe M, Vance DE, Elgin JM, Ball KK, Owsley C (2009) Mild cognitive impairment and everyday function: an investigation of driving performance. *J Geriatr Psychiatry Neurol* **22**, 87-94.

[57] Urlings JHJ, Cuenen A, Brijs T, Lutin M, Jongen EMM (2018) Aiding medical professionals in fitness-to-drive screenings for elderly drivers: development of an office-based screening tool. *Int Psychogeriatr* **30**, 1211-1225.

[58] Carr DB, Barco PP, Wallendorf MJ, Snellgrove CA, Ott BR (2011) Predicting road test performance in drivers with dementia. *J Am Geriatr Soc* **59**, 2112-2117.

[59] Ott BR, Davis JD, Papandonatos GD, Hewitt S, Festa EK, Heindel WC, Snellgrove CA, Carr DB (2013) Assessment of driving-related skills prediction of unsafe driving in older adults in the office setting. *J Am Geriatr Soc* **61**, 1164-1169.

[60] Manning KJ, Davis JD, Papandonatos GD, Ott BR (2014) Clock Drawing

as a Screen for Impaired Driving in Aging and Dementia: Is It Worth the Time? *Archives of Clinical Neuropsychology* **29**, 1-6.

## Datasets

Table 1

Demographic and driving-related characteristics of the participants

| Variables | | Retired drivers (n) | Current drivers (n) | $\chi^2$ / *t* | *p* | Cramer's V |
|---|---|---|---|---|---|---|
| **Age, y** | Total<br>Mean (SD) | 24<br>82.04(5.513) | 23<br>76.39(6.913) | 3.105[a] | 0.003 | - |
| **Gender** | Female<br>Male | 14<br>10 | 6<br>17 | 4.996[b] | 0.039 | 0.326* |
| **Diagnosis** | SCD<br>MCI<br>AD | 0<br>5<br>19 | 5<br>14<br>4 | 19.181[c] | <0.001 | 0.636** |
| **Driving patterns** | unable to drive<br>restricted<br>unconditionally | 21<br>3<br>0 | 0<br>8<br>15 | 38.269[b] | <0.001 | 0.902** |
| **Traffic accidents, n** | 0<br>1~4 | 18<br>4 | 15<br>8 | 1.585[b] | 0.314 | 0.188 |
| **Driving frequency** | never<br>sometimes<br>everyday | 23<br>1<br>0 | 1<br>10<br>12 | 39.527[b] | <0.001 | 0.917** |
| **Duration of driving experience, y** | 3~20<br>21~50<br>51~70 | 4<br>13<br>3 | 1<br>10<br>12 | 7.237[c] | 0.020 | 0.415* |

*$p < 0.05$, **$p < 0.001$, [a]. Independent Samples *t* Test., [b]. Pearson Chi-Square, [c]. Fisher's Exact Test; SCD: subjective cognitive decline; MCI: mild cognitive impairment; AD: Alzheimer's disease

Table 2

The scores of the neuropsychological tests of the participants

| Variables | | Retired drivers | Current drivers | *p* values | | | *cohen's d* |
|---|---|---|---|---|---|---|---|
| | | | | *unadjusted* | *age adjusted* | *gender adjusted* | |
| **MMSE**[a] | n<br>Mean (SD) | 24<br>18.67 (6.26) | 23<br>26.13(2.89) | <0.001 | <0.001 | <0.001 | 1.520 |
| **TMT-A**[b] | n<br>Median ($Q_L$, $Q_U$) | 23<br>94 (70, 295) | 21<br>57 (46.5, 64) | <0.001 | 0.002 | <0.001 | 1.208 |
| **TMT-B**[b] | n<br>Median ($Q_L$, $Q_U$) | 23<br>312 (312, 312) | 21<br>154 (95.5, 274) | <0.001 | 0.002 | <0.001 | 1.289 |
| **BDT**[b] | n<br>Median ($Q_L$, $Q_U$) | 12<br>19.17 (5.80) | 18<br>29.40 (7.90) | 0.001 | 0.011 | 0.001 | 1.226 |
| **ADAS-Cog**[a] | n<br>Mean (SD) | 13<br>13.7 (4.97) | 21<br>10.18 (3.95) | 0.03 | 0.076 | 0.021 | 0.800 |
| **LM I**[b] | n<br>Median ($Q_L$, $Q_U$) | 18<br>1 (0, 3) | 21<br>4 (3, 7.5) | <0.001 | 0.014 | <0.001 | 1.213 |
| **LM Ⅱ**[b] | n<br>Median ($Q_L$, $Q_U$) | 18<br>0 (0, 0) | 21<br>1 (0.5, 3.5) | <0.001 | 0.114 | 0.015 | 0.890 |
| **CDT**[b] | n<br>Median ($Q_L$, $Q_U$) | 22<br>8 (3.5, 10) | 22<br>10 (9, 10) | 0.002 | 0.007 | 0.002 | 1.079 |

[a]. Independent Samples *t* Test, [b]. Mann-Whitney *U* Test. MMSE: mini-mental state examination; TMT: trail making test; BDT: block design test; ADAS-Cog: Alzheimer's disease assessment scale–cognitive subscale; LM: Logical memory; CDT: clock drawing test.

Table 3

The results of the reaction tests of the participants with SCD, MCI, and AD

| Diagnosis | sim-RT (s) | sim-dRT (s) | com-RT (s) | com-dRT (s) | eR (n) |
|---|---|---|---|---|---|
| **SCD (n=4)** | 0.515 (0.031) | 0.149 (0.081) | 0.976 (0.102) | 0.128 (0.025) | 1.50 (1.732) |
| **MCI (n=14)** | 0.477 (0.085) | 0.161 (0.081) | 0.970 (0.192) | 0.225 (0.053) | 12.43 (6.161) |
| **AD (n=3)** | 0.829 (0.092) | 0.380 (0.042) | 1.137 (0.287) | 0.301 (0.048) | 15.33 (14.189) |
| ***F*** | 24.315 | 10.477 | 0.943 | 11.227 | 4.422 |
| ***p*** | <0.001 | 0.001 | 0.408 | 0.001 | 0.027 |
| **1- $\beta$ (post hoc)** | 0.9998 | 0.9276 | - | 0.9453 | 0.4998 |
| **Pairwise comparison**[a] | SCD<AD** | SCD<AD* | - | SCD<MCI* | SCD<MCI* |
| | MCI<AD** | MCI<AD* | - | SCD<AD* | |

*p < 0.05. **p < 0.001. [a]. Bonferroni-adjusted significance tests. SCD: subjective cognitive decline; MCI: mild cognitive impairment; AD: Alzheimer's disease; sim-RT: the mean of reaction time of the simple reaction test; sim-dRT: the deviation of reaction time of the simple reaction test; com-RT: the mean of reaction time of the complex reaction test; com-dRT: the deviation of reaction time of the complex reaction test; eR: the number of erroneous reactions in the complex reaction test

Table 4

The results of the driving test of the 16 participants

| Variables | | Frequency<br>Median ($Q_L$, $Q_U$) | Evaluation Ranking<br>< average (person) | <br>≧ average (person) |
|---|---|---|---|---|
| Starting & Stopping | sudden starting | 1.5 (0, 4) | 4 | 12 |
| | traffic lights or stop sign violations | 2 (1, 2.75) | | |
| | sudden braking | 0 (0, 0.75) | | |
| Signaling | forgetting to use turn signals | 2 (1, 2.5) | 3 | 13 |
| | using turn signals incorrectly | 0.5 (0, 1) | | |
| Safety check | inappropriate rear safety check | 0 (0, 0) | 0 | 16 |
| | overlooking dangerous vehicles ahead | 0 (0, 1) | | |
| | overlooking signboards or traffic lights | 1 (0, 1) | | |
| Positioning | stopping inappropriately | 1.5 (1, 2) | 0 | 16 |
| | out of lane | 0 (0, 0) | | |
| | inappropriate inter-vehicle distance and lateral spacing | 0 (0, 0) | | |
| | centerline crossings | 0 (0, 0) | | |
| Speeding | range of driving over the speed limit (%) | 0 (0, 0.4) | 0 | 16 |
| | overspeed - the speed limit (km/h) | 0 (0, 5.30) | | |
| | intersection speed(km/h) | 10.31(8.11, 13.15) | | |
| Overall | going the wrong way | 0 (0, 0) | 8 | 8 |
| | near-miss accidents | 0 (0, 1) | | |
| | crashes and collisions | 0.5 (0, 1) | | |

Table 5

Correlative analyses of driving parameters and the scores of neuropsychological tests

| **Driving Performance** | | **MMSE** | | | | | **Other Neuropsychological Tests** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Domains** | **Parameters** | Total score | Orientation to time | Orientation to place | Attention & Calculation | Recall | TMT-A | TMT-B | BDT | ADAS-Cog | CDT |
| Reaction | sim-RT (s) | -0.685* | -0.185 | 0.052 | -0.724** | -0.479 | 0.492 | 0.694** | -0.487 | 0.460 | -0.293 |
| | sim-dRT (s) | -0.685* | -0.228 | 0.122 | -0.693** | -0.589* | 0.531* | 0.595* | -0.229 | 0.433 | -0.389 |
| | com-RT (s) | -0.368 | -0.256 | 0.191 | -0.368 | 0.065 | 0.562* | 0.634* | -0.369 | 0.455 | -0.158 |
| | com-dRT (s) | -0.753** | -0.584* | 0.017 | -0.625** | -0.485 | 0.370 | 0.814** | -0.200 | 0.493 | -0.283 |
| | eR (n) | -0.430 | -0.685** | <0.001 | -0.319 | -0.391 | -0.106 | 0.427 | -0.203 | 0.392 | -0.090 |
| Stopping | SB (n) | -0.707** | -0.461 | -0.505* | -0.426 | -0.541* | 0.023 | 0.312 | -0.560* | 0.758** | -0.244 |
| Signaling | FUTS (n) | -0.255 | -0.460 | 0.089 | -0.250 | 0.045 | 0.452 | 0.608* | -0.159 | -0.002 | 0.185 |
| Safety check | IRSC(n) | -0.425 | -0.444 | -0.537* | -0.376 | -0.237 | -0.062 | 0.343 | -0.208 | 0.310 | -0.153 |
| | OSTL(n) | -0.105 | -0.511* | -0.076 | 0.006 | -0.045 | 0.296 | 0.247 | 0.232 | 0.052 | -0.044 |
| Positioning | CC (n) | -0.582* | -0.607* | -0.332 | -0.550* | -0.447 | 0.163 | 0.503 | -0.423 | 0.538* | -0.392 |
| Speeding | R-DOSL (%) | 0.174 | 0.625** | 0.359 | -0.182 | 0.085 | -0.237 | -0.260 | 0.232 | -0.215 | -0.470 |
| | OS-SL (km/h) | 0.182 | 0.586* | 0.359 | -0.154 | 0.090 | -0.262 | -0.260 | 0.235 | -0.194 | -0.444 |
| Overall | GWW (n) | -0.189 | -0.055 | 0.181 | -0.391 | -0.278 | 0.310 | 0.343 | -0.381 | 0.434 | -0.624** |

*p < 0.05. **p < 0.01. Sim-RT: the mean of reaction time of simple reaction test; sim-dRT: the deviation of reaction time of simple reaction test; com-RT: the mean of reaction time of complex reaction test; com-dRT: the deviation of reaction time of complex reaction test; eR: the number of erroneous reactions of complex reaction test; SB: sudden braking; FUTS: forgetting to use turn signals; IRSC: inappropriate rear safety check; OSTL: overlooking signboards or traffic lights; CC: centerline crossings; R-DOSL: range of driving over the speed limit; OS-SL: overspeed - the speed limit; GWW: going the wrong way; MMSE: mini-mental state examination; TMT: trail making test; BDT: block design test; ADAS-Cog: Alzheimer's disease assessment scale–cognitive subscale; CDT: clock drawing test.

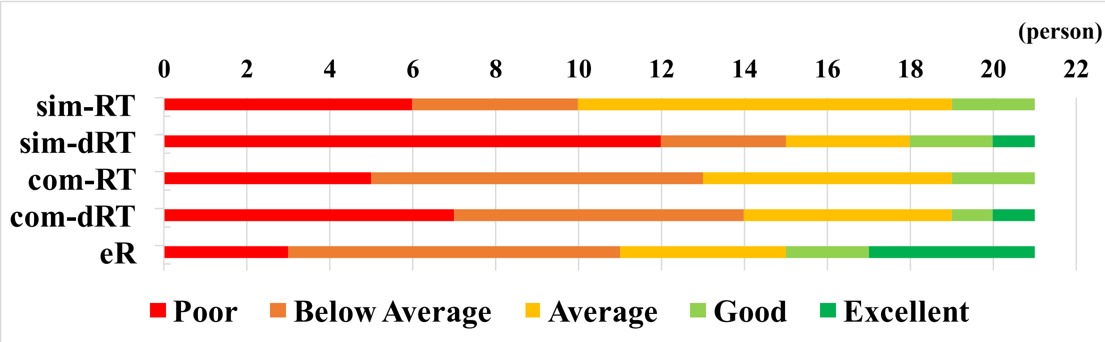



Figure. 1

The evaluation ranking of the reaction tests of the 21 participants

sim-RT: the mean of reaction time of the simple reaction test; sim-dRT: the deviation of reaction time of the simple reaction test; com-RT: the mean of reaction time of the complex reaction test; com-dRT: the deviation of reaction time of the complex reaction test; eR: the number of erroneous reactions in the complex reaction test

**Supplementary Material**


Supplementary Figure 1. The driving simulator: Honda Safety Navi (Honda Motor Co., Tokyo, Japan)

運転能力測定結果

| | |
|---|---|
| 測定者NO.: 000 | 測定日: 2018/12/04 |
| 氏名: ほう | 年齢・性別: 26 歳 女性 |

評価ランク

| 優秀 A | 良好 B | 普通 C | 注意 D | 不安 E |
|---|---|---|---|---|

## ■単純反応測定

| | | | 〔健常者30～50代比較〕 | 〔健常者同年代比較〕 |
|---|---|---|---|---|
| 反応動作の速さ | 平均時間 | 0.545886 秒 | 〔 D 〕 | 〔 E 〕 |
| 反応動作のムラ | 標準偏差 | 0.070733 秒 | 〔 C 〕 | 〔 D 〕 |

反射的な動作が遅く、突発的な出来事に対して対応がかなり遅れる傾向にあります。
反応速度のムラがやや大きく、状況の変化に対する動作が不安定になりがちです。

## ■選択反応測定

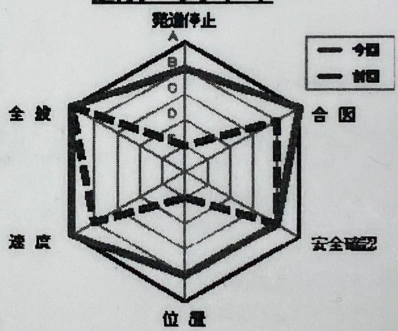
| | | | 〔健常者30～50代比較〕 | 〔健常者同年代比較〕 |
|---|---|---|---|---|
| 反応動作の速さ | 平均時間 | 0.779221 秒 | 〔 C 〕 | 〔 D 〕 |
| 反応動作のムラ | 標準偏差 | 0.063302 秒 | 〔 A 〕 | 〔 B 〕 |
| 誤反応 | 回数 | 1 回 | 〔 B 〕 | 〔 B 〕 |

判断を伴った操作がやや遅く、複雑な状況での対応が遅れ気味です。
動作のムラが小さく、判断を伴う操作は安定しています。

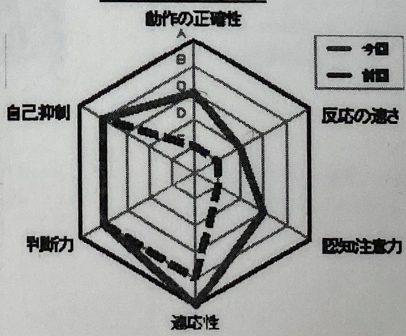
## ■走行データ

| 項目 | 区分 | 結果 | 評価 |
|---|---|---|---|
| 発進停止 | 急発進操作 | 1 回 | B |
| | 停止線・踏切・赤信号での不停止 | 1 回 | |
| | 急ブレーキ操作 | 0 回 | |
| | 駐車の仕方(指定場所駐車) | ○ | |
| 合図 | 合図(ウインカー)なし | 0 回 | A |
| | 合図方向違い | 0 回 | |
| 安全確認 | 後方確認不適 | 0 回 | B |
| | 左右確認不適 | - 回 | |
| | 前方危険車両等の見落とし | 0 回 | |
| | 信号、標識、標示等の見落とし | 1 回 | |
| 位置 | 停止位置不適 | 2 回 | B |
| | 走行車線不適 | 0 回 | |
| | 車間距離、側方間隔不適 | 0 回 | |
| | 車線のはみ出し | 0 回 | |
| 速度 | 速度超過割合 | 2.5 % | A |
| | 速度超過分の平均速度 | 6.2 km/h | |
| | 右左折時の交差点内平均速度 | 15.7 km/h | |
| 全般 | 進路間違い<指示看板見過ごし> | 1 回 <無> | A |
| | ヒヤリハット(衝突寸前) | 0 回 | |
| | 事故発生 | 0 回 | |

走行データチャート




運転特性チャート




| 総合コメント | 担当者 |
|---|---|
| | |

Supplementary Figure 2. The report of driving performance

Supplementary Table 1

The driving simulator test overview

| Tests | | Details | |
|---|---|---|---|
| Reaction Tests | Simple reaction test | 1. Step on the accelerator pedal to start the car and increase to its maximum speed of 40 km/h and then retain it.<br>2. Release the accelerator pedal as soon as the rear lights of the car ahead turn green, and then step on the pedal right away. | |
| | Complex reaction test | 1. Step on the accelerator pedal to start the car and increase to its maximum speed of 40 km/h and then retain it.<br>2. Release the accelerator pedal and step on the brake with your right foot once the rear lights of the car ahead turn red, and then step on the accelerator pedal right away.<br>3. only release the accelerator pedal once the rear lights of the car ahead turn yellow, then step on the accelerator pedal to the maximum right away.<br>4. Continue to step on the accelerator pedal to its maximum, once the rear lights of the car ahead turn navy. | |
| Driving Test | | Traffic scenarios and tasks | Environment |
| | | 1. Safety check before entering the road. | Straight road with good visibility from the parking lot; speed limit: 50 km/h |
| | | 2. Changing lanes. | Branch road with good visibility in a busy street; speed limit: 50 km/h |
| | | 3. Proper sequence when turning right and a bicycle abruptly crosses the intersection. | Intersection in a lane street;<br>speed limit: 50 km/h |
| | | 4. The priority of vehicles coming from the right when merging. | Merging area with good visibility in a coastal road; speed limit: 40 km/h |
| | | 5. The oncoming traffic on the opposite lane when turning right. | Intersection in a residential street; speed limit: 40 →30km/h |
| | | 6. Moving at an intersection without traffic lights. | T-junction with poor visibility in a narrow residential street without a road division; speed limit: 30 km/h |
| | | 7. Predicting signal changes. | Intersection at a cross of a busy street and a residential street;<br>speed limit: 30→50km/h |
| | | 8. An unexpected motorcycle approaching from the oncoming vehicle when turning right. | Intersection in a busy street;<br>speed limit: 50 km/h |
| | | 9. Overtaking the work vehicle which is parked alongside the road. | Straight road with good visibility in a busy street; speed limit: 50→40km/h |
| | | 10. Unexpected motorcycle approaching when turning left. | Intersection in a busy street;<br>speed limit: 50 km/h |
| | | 11. A child suddenly runs across the road when approaching the pedestrian crossing. | Straight road with good visibility in a school area (road sign) without traffic lights; speed limit: 40 km/h |
| | | 12. Consecutive curve on a ramp. | Mountain road (an 8% uphill slope) with continuous curve;<br>speed limit: 40 km/h |