The effects of amnesia on driving performance in elderly drivers

Naoko Kawano (n-kawano@med.nagoya-u.ac.jp)
Department of Psychiatry, Graduate School of Medicine,
Nagoya University, Japan.

Kunihiro Iwamoto (iwamoto@med.nagoya-u.ac.jp)
Department of Psychiatry, Graduate School of Medicine,
Nagoya University, Japan.

Kazutoshi Ebe (whitejam@nifty.ne.jp)
Toyota Central R&D Labs., Inc., Japan.

Katsuyuki Ukai (ukai777@kamiiida-hp.jp)
Kamiiida daiichi General hospital, Japan.

Yusuke Suzuki (yus@med.nagoya-u.ac.jp)
Department of Geriatrics, Graduate School of Medicine,
Nagoya University, Japan.

Hiroyuki Umegaki (umegaki@med.nagoya-u.ac.jp)
Department of Geriatrics, Graduate School of Medicine,
Nagoya University, Japan.

Tetsuya Iidaka (iidaka@med.nagoya-u.ac.jp)
Department of Psychiatry, Graduate School of Medicine,
Nagoya University, Japan.

Norio Ozaki (ozaki-n@med.nagoya-u.ac.jp)
Department of Psychiatry, Graduate School of Medicine,
Nagoya University, Japan.

Abstract

Cognitive dysfunction caused by some neurodegenerative diseases is associated with an increased risk of traffic accidents. Previous studies have reported inconsistent results for prodromal and early stages of dementia. Few studies have directly compared the effects on driving performance of amnestic subtype of mild cognitive impairment (aMCI) with those by normal aging in elderly drivers. The present study examines the association between cognitive decline and driving ability in elderly drivers with aMCI. The participants were 19 healthy young adults (HYA), 26 healthy elderly adults (HEA), and 12 elderly patients with aMCI. All performed a road-tracking, a car-following, and a harsh-braking task on a driving simulator (DS). Elderly participants also completed cognitive assessment tasks including measures of memory performance. All MCI participants showed a well-defined memory decline, and demonstrated significantly decreased performance on the car-following and road-tracking tasks as compared with the HYA group. However, the aMCI group also demonstrated significantly decreased performance on the car-following task as compared with HEA. In elderly participants, the car-following performance was positive correlated with the score on the Trail Making Test-B. This evidence indicates a difference for driving ability between individuals with symptomatic memory impairment and the aging-related memory of normal controls. This difference may be associated with flexibility of visual attention and executive function.

Keywords: mild cognitive impairment, driving simulator, Trail Making Test, elderly driver, normal aging.

Introduction

Driving is a specialized and complex action that requires the use of extensive cognitive abilities. Age-related dysfunction of the central nervous systems in people with dementia, such as symptoms caused by Alzheimer's disease, may influence driving. Studies have found that drivers with dementia have 2.5 to 4.7 times the risk of an automobile accident compared to cognitively intact elderly drivers (Cooper, Tallman, Tuokko, & Beattie, 1993; Molnar, Patel, Marshall, Man-Son-Hing, & Wilson, 2006). Fatal motor vehicle crash rates (per miles driven) show a U-shape curve with the highest rates among the youngest and oldest drivers (Hakamies-Blomqvist, Sirén, & Davidse, 2004).

Cognitive limitations not only from some age-related neurodegenerative diseases but also from aging-related normal changes are associated with an increased risk of being involved in a traffic accident. Epidemiological studies demonstrated that elderly patients with mild dementia are

high-risk drivers, as a group, compared with cognitively intact drivers (Man-Son-Hing Marshall, Molnar, & Wilson, 2007). However, there is little evidence showing the difference in the actual driving behaviors of individuals in these two groups (Iverson et al., 2010). A substantial number of patients with a Clinical Dementia Rating Scale (CDR: Morris, 1993) scores of 0.5-1.0, which are in the preclinical or early stage of dementia, were still able to drive safely in an on-road driving test (Brown et al., 2005). Iverson et al. recommend that studies are needed to identify the appropriate predictive factors for risky driving in patient with prodromal and mild dementia, and then to develop a composite system of rating risk for drivers in the early stages of dementia.

"Mild cognitive impairment (MCI)" is conceptualized as a transitional state between normal cognitive aging and clinical dementia, with amnestic and non-amnestic subtypes of MCI have been defined (Petersen & Morris, 2005). The amnestic subtype of MCI (aMCI) is characterized by memory impairment, and is often operationalized as the Clinical Dementia Rating Scale score of 0.5. People with aMCI progress to Alzheimer's disease (AD) at a rate of 8-15% per year, as compared to the normal aging with a dementia progression rate of 1-2% per year (Petersen et al., 2001). Therefore aMCI is considered a prodromal syndrome of AD, and often precedes the onset of dementia.

Individuals with MCI may be at risk for decline in everyday complex functions, including driving. However, we have limited information about the crash risk and driving behaviors of individuals with clinical MCI (Man-Son-Hing et al., 2007). Recently, Frittelli et al. (2009) reported that MCI had a limited effect on driving performance on a driving simulator, and that AD patients' unsafe driving behavior was not predicted by their MMSE scores. They compared patients with mild AD and with MCI and age-matched neurologically normal controls. However, it is not clear which cognitive characteristics of individuals with MCI do endorse safer driving performance or which do not.

O'Connor, Edwards, Walley, and Crowe (2011) reported associations between driving behaviors, assessed by a self-report questioners, and classification of MCI. Their sample was a subset of the mobility data ($n = 2381$) in the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study ($N = 2802$), and the subset included 82 individuals with the aMCI, 140 individuals with the non-amnestic subtype of MCI, and 82 individuals with multi-domain subtype of MCI, and normal controls. They investigated psychometrically well-defined MCI at baseline as a predictor in a five years follow-up of changes in driving behaviors. Their results suggested that MCI status predicted declines in driving frequency and increases in driving difficulty. The classification of MCI subtypes predicted different trajectories of changes for driving frequency and driving difficulty. The amnestic and non-amnestic groups showed greater declines in driving frequency than the multi-domain group and the normal controls. The amnestic and non-amnestic groups showed increases for driving difficulty

in common situations, whereas the multi-domain group showed a greater increase for driving difficulty only in complex situations. The aMCI showed decline in driving frequency but did not self-report driving difficulty. The authors discussed these findings from the viewpoint of self-regulation and risk perception in their groups' driving behaviors. They suggested that these findings may reflect impaired risk perception related to amnesia. Objective assessment data of driving performance is still need to determine actual risk assessment.

In the present study, we considered these remaining problems, and examined individuals with clinical aMCI and age-matched memory-intact individuals and normal young adults to evaluate driving performance using a driving simulator (DS). Although many consider road testing to be the gold standard to evaluate driving competence, road tests are costly and can be dangerous when the driver is incompetent. The DS appears to be a safe and cost-effective method for the objective evaluation of driving performance.

In order (1) to examine how cognitive state may impair driving performance in patients with a prodromal stage of dementia, and (2) to identify cognitive variables explaining the deterioration of driving performance in the aMCI group, we designed a case-control study to compare the driving performance decline between adults with clinical aMCI and elderly adults with an intact memory, based on the performance of normal young adults.

Method

Participants

We recruited 19 healthy young adults (HYA: 39.3 years old, SD = 6.5), 26 healthy elderly adults (HEA: 70.0 years old, SD = 6.1), and 12 elderly patients with aMCI (71.8 years old, SD = 7.6). The participants were naïve with regard to this study, and were paid for their participation. All were active drivers with more than 10 years of driving experience. They all had normal or corrected-to-normal vision, and no history of cerebral vascular events.

The Nagoya University Graduate School of Medicine and Nagoya University Hospital ethics review committee approved this study. Written informed consent was obtained from all participant prior to their participation.

All participants were examined by an experienced psychologist who used the same task order. They had no history of psychiatric problem as assessed by the Structured Clinical Interview for DSM-IV (SCID: First, Spitzer, Gibbon, & Williams, 1997). The HYA and HEA individuals were recruited in non-clinical setting, and had no impairment in activities daily living (ADL) and no evidence of dementia on the Clinical Dementia Rating Scale (CDR = 0.0). They showed no evidence of cognitive decline on enrollment screening questionnaire. The patients with aMCI were recruited in clinical setting. All were diagnosed according to the criteria for MCI, provided by the Petersen group. All of the aMCI group had a CDR = 0.5.

Amnesia confirmation The confirmation of amnesia was identified using psychometric methods. All elderly participants were assessed using structured neuro-psychological tests, including the Mini-Mental State Examination (MMSE: Folstein, Folstein, & McHugh, 1975), to their confirm general cognitive state, and the Logical Memory delayed recall subtests of the Wechsler Memory Scale-Revised (WMS-R: Wechsler, 1987) to confirm memory function.

Cognitive functions Additional neuropsychological measures, which have been used in previous studies related to complex driving tasks, were also used. The digit span subtests of the Wechsler Adult Intelligence Scale-Revised (WAIS-R: Wechsler, 1981) and the Trail Making Test (TMT) -A were used to assess simple attention and concentration function. The TMT-B and the Modified Stroop Test were used to assess attention flexibility and executive function. The Clock Drawing Test (CDT) was used to assess visuospacial function.

Tasks

Driving performance Daily driving skills associated with traffic accidents were measured by a road-tracking, a car-following, and a harsh-braking task. These tasks were run on a DS manufactured by Toyota Central R&D Labs., Inc. (Nagakute, Japan).

The car-following task involved a straight two-lane road with no other traffic, except for a single preceding car. When the preceding car decelerated, its brake lights came on. As the preceding car accelerated (to 60 km/h) or decelerated (to 40 km/h), the participant was required to maintain a distance between the cars as close to 5 m as possible. The car-following distance (m) was recorded every 20 ms. Performance was measured as the coefficient of variation (CV) obtained by dividing the standard deviation of the distance between the cars by the mean value (see Uchiyama, Ebe, Kozato, Okada, & Sadato, 2003). Therefore, a smaller distance CV value (DCV) indicated better performance. The test duration was 5 min.

The road-tracking task required the participant to drive at a constant speed of 100 km/h, while stabilizing the vehicle at the center of a gently winding road. The standard deviation of the lateral position (SDLP; in cm), which indicates weaving, was used as performance measures. Recordings were made every 20 ms during the test, which lasted for a period of 5 minutes.

The harsh-braking task included a straight two-lane road with no traffic, but with humanoid models on either side of the left lane. The humanoid models randomly ran onto the road as the participant's car approached. The participant was instructed to maintain a constant speed of 50 km/h and to avoid hitting the humanoid models by harsh braking as quickly as possible. The brake reaction time (BRT; in ms) was used as a measure of the cognitive psychomotor performance, including attention efficiency (see Ridout & Hindmarch, 2001). Each test consisted of 7 BRT trials over

a 5-min period, and the mean BRT was calculated from these results.

The driving performance evaluation using the DS was performed after the neuropsychological testing was complete. Before starting the evaluation, each driver was familiarized with the DS in three practice driving trials. During the practice, the driving performances of the HEA participants had plateaued (Kawano et al., in press). Within one week of the practice session, the test session was performed for each DS task, in the following order: the road-tracking, car-following, and harsh-braking task.

Statistical analyses

To compare the demographic data including age, education, and the neuropsychological test performances among the groups, Kruskal-Wallis tests were carried out. Post hoc multiple comparisons were computed by the Mann-Whitney U test with the ordinary Bonferroni adjustment. DS values were compared among groups by one-way ANOVAs, after applying log transformations to normalize the data. Post hoc multiple comparisons were computed by the Tukey HSD. To analyses the relationship between the performance of DS task and some neuropsychological values, correlational analyses based on the Spearman's ρ and multiple linear regression analyses were carried out.

All Statistical analysis was performed with the SPSS. A P-value of less than 0.05 was considered to indicate statistical significance.

Results

The characteristics of participant group are shown in Table 1. No significant differences were shown in age and education level between NEA and aMCI groups. There were significant differences between the two elderly groups for the MMSE and the Logical Memory delayed recall subtests of the WMS-R. All NEA individuals had MMSE scores over 26, and Logical Memory delayed recall performances over 11. On the other hand, all individuals with aMCI had a score of 9 or below on the Logical Memory delayed recall task.

To examine whether aMCI affected DS performance, the performance on each of the three DS tasks were compared among the groups. Figure 1 displays the groups' mean performance for each driving task. For the car-following task, the ANOVA revealed a main effect of group ($F(2, 54) = 16.61$, $p = 0.00$, $\eta^2 = 0.38$). Multiple comparisons by Tukey HSD tests showed significant differences among all groups. The performance of NYA was significant higher than aMCI and NEA ($t = 5.76$, $p = 0.00$, $r = 0.73$; $t = 2.69$, $p = 0.03$, $r = 0.38$), and NEA was significant higher than aMCI ($t = 3.76$, $p = 0.00$, $r = 0.53$). For the road-tracking task, the ANOVA revealed a main effect of group ($F(2, 54) = 17.62$, $p = 0.00$, $\eta^2 = 0.40$). Multiple comparison by Tukey HSD tests showed significant differences between NYA and aMCI. The performance of NYA was higher than aMCI and NEA ($t = 5.53$, $p = 0.00$, $r = 0.71$; $t = 4.51$, $p = 0.00$, $r =$

Table 1: Characteristics of each group: Mean (Standard Deviations)

	aMCI		NEA		NYA	
Sex (female/male)	2/10		11/15		1/18	
Age (years)	71.8	(7.6)	70.0	(6.1)	39.3	(6.5)
Education (years)	13.4	(3.5)	14.4	(2.8)	16.6	(1.7)
Cognitive characteristics						
Mini-Mental State Examination	25.5	(2.9)	28.5	(1.4)		
WMS-R Logical Memory: delayed recall	4.6	(3.7)	20.0	(5.3)		

Note. aMCI = amnestic type of mild cognitive impairment, NEA = normal elderly adults, NYA = normal young adults, WMS-R = Wechsler Memory Scale-Revised.

0.56), but there was no significant difference between NYA and aMCI ($t = 1.95$, $p = 0.14$, $r = 0.31$). For the harsh-braking task, 12 persons had missing values caused by technical problems or the participants. A one-way ANOVA was performed for 10 aMCI participants, 19 NEA participants, and 16 NYA participants. The analysis revealed no main effect of group ($F(2, 42) = 3.21$, $p = 0.05$, $\eta^2 = 0.13$). There were no significant differences between groups.

Correlational analyses were conducted to examine the relationship between the performance on the car-following task (DCV) and some neuropsychological values in elderly groups. In the elderly group mixed NEA and aMCI, there were significant positive correlations between the DCV on the car-following task and TMT-A, TMT-B, and the Modified Stroop Test ($\rho = 0.47$, $p = 0.00$; $\rho = 0.54$, $p = 0.00$; $\rho = 0.38$, $p = 0.02$). No significant correlations were found between DCV and CDT ($\rho = -0.18$, $p = 0.30$), or DCV and the WAIS-R digit span subtest ($\rho = -0.31$, $p = 0.06$). In the aMCI group only, there were significant positive correlations between DCV and TMT-A, TMT-B, and the Modified Stroop Test ($\rho = 0.47$, $p = 0.00$; $\rho = 0.54$, $p = 0.00$; $\rho = 0.38$, $p = 0.02$). No significant correlations were found between DCV and CDT ($\rho = -0.18$, $p = 0.30$), or DCV and the WAIS-R digit span subtest ($\rho = -0.31$, $p = 0.06$). In addition, to confirm whether these variables, which are significantly associated with DCV, predicted the car-following performance more than just memory impairment did, multiple linear regression analyses were carried out. Adjusting for the delayed recall performance on the WMS-R Logical Memory, the predictive strength of TMT-A, TMT-B, and the Modified Stroop Test was confirmed using log transformation DCV as an independent variable. Results of multiple linear regression analyses are displayed in Table 2. The results showd that the TMT-B performance significantly predicts the car-following performance after adjusting for the severity level of amnesia ($\beta = 0.40$, $p = 0.04$, $R = 0.63$, adjusted $R^2 = 0.40$).

Discussion

This study has provided clear evidence that late-life amnesia harms driving performance. An elderly sample with these characteristics showed that significantly decreased performance on the car-following and road-tracking tasks as compared with the normal young adults. However, the results showed a difference between individuals with symptomatic memory impairment and normal aging-related characteristics for driving abilities. There was no significant difference among the elderly groups on the road-tracking task. In contrast, there was a significant difference between groups on the car-following task. These results indicate that aMCI affects driving performance in patients with a prodromal stage of dementia, but normal aging also affects performance.
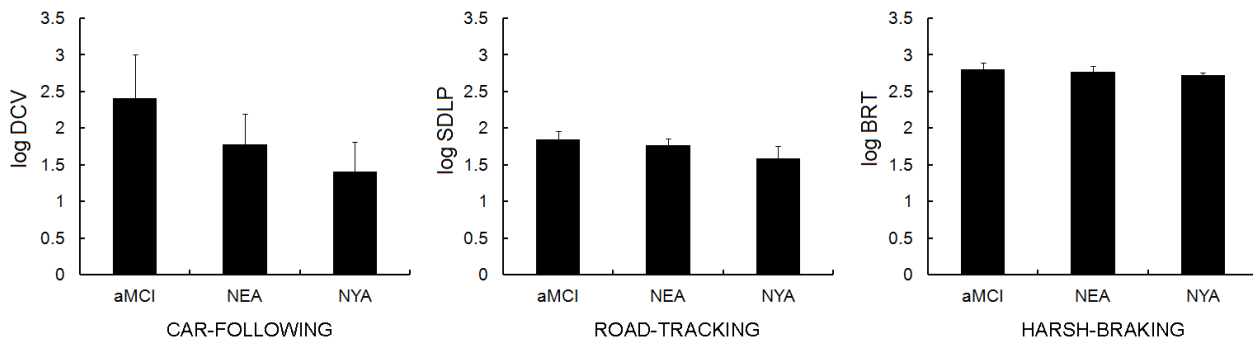

Figure 1: Means for DS task performances for each group.

Note. DCV = distance coefficient of variation, SDLP = standard deviation of the lateral position, BRT = brake reaction time, aMCI = amnestic subtype of mild cognitive impairment, NEA = normal elderly adults, NYA = normal young adults.

Table 2: Association between the performance for the car-following task and
neuropsychological test scores in the elderly group.

	R	R^2	adjusted R^2	B	β	P		95% confidence interval of B		
TMT-A	0.577	0.333	0.292	0.011	0.167	0.318		-0.011	-	0.033
WMSR-delayed recall				-0.069	-0.475	0.007	*	-0.118	-	-0.021
TMT-B	0.629	0.396	0.359	0.007	0.395	0.040	*	0.000	-	0.013
WMSR-de				-0.042	-0.290	0.124		-0.097	-	0.012
Modified Stroop Test	0.574	0.329	0.290	0.023	0.260	0.140		-0.008	-	0.053
WMSR-delayed recall				-0.057	-0.382	0.033	*	-0.109	-	-0.005

Note. TMT = Trail Making Test, WMSR = Wechsler Memory Scale-Revised: Logical Memory.

Second, the different findings may be due to sample characteristics of MCI group and age matched control group. We checked that all the MCI participants showed a well-defined memory decline, and that all the normal elderly controls had intact memory and normal cognitive characteristics. In the present study, we examined these elderly people with amnesia and age-matched memory intact controls to evaluate driving performances using driving simulator, and compared their performance with normal young adults. Frittelli et al. (2009) compared among mild AD patients, people with MCI, and age-matched neurologically normal controls. We considered the problems involved with normal aging, and we found that not only aMCI but also normal-aging impaired driving performance. Our results indicated that MCI impaired car-following accuracy.

Simulated driving was found to be significant impaired in participants with aMCI. To identify cognitive variables explaining the decrement in car-following performance in late-life, correlational analyses were conducted. Although car-following performance was significantly related to performance on the TMT-A, TMT-B, and the Modified Stroop Test in our study sample, the correlations with the MMSE were not significant. These results are in agreement with previous studies showing that the MMSE, a widespread dementia screening tool, is limited as a predictive instrument. A few studies have reported a significant relation of MMSE scores to driving simulator and on-road driving performance (e.g. Fitten et al., 1995), but many studies have indicated that MMSE scores did not discriminate unsafe drivers from elderly drivers with unimpaired performance (Brown et al., 2005; Fox, Bowden, Bashford, & Smith, 1997; O'Neill et al., 1992). Also, general cognitive decline assessed by the MMSE is not found at the start of brain degeneration disease, and the aMCI operational criteria are conditional on a normal score on the MMSE. Thus, our elderly sample had less variability in MMSE scores. For patients with a prodromal stage of dementia, the MMSE is not useful as a predictor of safe driving, which has been shown in our results and numerous other studies with inconsistent results.

We found a linear relationship between performance on the TMT-B and the car-following task, and this relationship remained after adjusting for the degree of symptomatic memory impairment. It is possible that the TMT-B is a useful tool for classifying elderly drivers as to whether they would pass or fail on the car-following task. The TMT is associated with attention flexibility and executive function (Lezak, 2004). The difference between unsafe drivers and persons with unimpaired performance may be associated with the flexibility of visual attention and executive function. Particularly, the TMT-B assesses more precisely the ability to alternate between two cognitive sets of stimuli, while the TMT-A of the test provides useful information concerning attention, visual scanning, speed of eye-hand coordination and information processing (Zalonis et al, 2008). These results suggest that persons with MCI who not only have memory impairment but also have difficulty gathering and processing information in parallel should drive under close supervision.

According to a cybernetic model of driving output, driver psychopathology is only one of a multitude of factors to consider (Moller, 2011). However, factors of driver psychopathology, normally limitations of psychological and neurophysiologic functioning, are associated with driving performance. Future studies need to evaluate the appropriate weighting of these risk factors in people with MCI, and develop criteria for re-evaluation of competency to drive.

Limitation The results of this study are constrained by certain limitations that are outlined below. Although we concluded this experiment based on the premise that participants in the three experimental groups were homogenous, there may have been differences in participants within each group. These differences may have been caused by misclassification of the amnesia status as a result of differences in age, educational level, or chronic physical disorder, although, the age and education level of the sample were not correlated with DS performance. We also did not consider the possibility that individuals with aMCI may have other impairments (a multiple-domain subtype) or not (amnestic single-domain subtype), because of the small sample size. Future studies need to consider these details of individuals in amnestic subtypes, non-amnestic subtypes, and multi-domain subtypes of MCI. Finally, whereas it is generally considered that road testing is the gold standard by which to evaluate driving

competence, we used the DS. There is a definite difference between on-road testing and DS tasks provide. The former can provide information on daily habits related to driving, whereas the latter provides objective assessment of competence. Future studies need to conduct longitudinal investigations of traffic incidents and compare them with changes in DS performance.

Acknowledgments

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