

Spatial navigation ability and gaze switching in older drivers: A driving simulator study

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Abstract

Objective: Driving ability in older people is affected by declining motor, cognitive and visual functions. We compared perceptual and cognitive skills and driving behaviour in a Japanese population.

Methods: We used a driving simulator to measure the effects of spatial navigation skills and eye movements on driving ability. Participants were 34 older and 20 young adults who completed a simulated driving task involving a lane change and a right turn at an intersection. We used an eye tracker to measure gaze. We measured visual recognition (Benton Judgment of Line Orientation Test (BJLO)), spatial navigation (Card-Placing Test (CPT A & B)), visual perception (Raven's Colored Progressive Matrices (RCPM)) and driving ability (Stroke Drivers' Screening Assessment).

Results: Older participants scored significantly lower on the BJLO, CPT-A & B and RCPM, showed a significant correlation between gaze time and CPT-A & B scores (both $p < .01$) and had a longer gaze time. There were significant between-group differences in saccade switching ($p < .01$ right turn), distance per saccade ($p < .05$ for right turn and lane change) and saccade total distance ($p < .05$ right turn; $p < .01$ lane change). There was an association between age and rate of gaze at the right door mirror ($p = 0.04$).

Conclusion: The findings indicate that older drivers have poorer eye movement control and spatial navigation. This is likely to result in delayed responses and difficulties in predicting the on-coming driving environment. Driving simulation could help older drivers in their driving abilities.

Keywords

Driving simulator, older drivers, eye movements, gaze time, spatial navigation

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Introduction

There has been much research on the effect of aging on the driving ability of older people (Richardson & Marottoli, 2003). Driving ability can be affected not only by age-related deterioration of physical function but also by problems in visual and cognitive function (Owsley & Ball, 1993). Occupational-therapy practitioners have an important role in supporting community mobility by evaluating who is at higher risk of having an accident when driving (American Occupational Therapy Association, 2005). The risk of traffic accidents associated with older drivers is attracting increased attention (Evans, L, 1991; Lee, 2010), and there is a need to appropriately evaluate the driving ability of older people and to provide them with

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feedback by occupational therapist. One method of measuring driving performance is to use a driving simulator (DS), which allows testing using virtual events, such as a pedestrian jumping out in front of the car or the vehicle in front braking suddenly. Previous research has shown a relationship between accidents in older drivers and the useful field of view, which represents the amount of information that can be obtained from a glance at the immediate surroundings without moving the head or eyes (Owsley, 1994). It is therefore important to evaluate not only a driver's ability to process events occurring ahead but also to test their wider visual field performance. Previous DS studies have analysed several driving performance factors, including the mean speed, speed variability (Hogema & van der Horst, 1994; Manser & Hancock, 2007), inter-vehicle distance (Dudek et al, 2006), the reaction time when using a hands-free telephone (Caird, Willness, Steel, & Scialfa, 2008), changes in heart rate before and after driving, measurement of steering wheel operation (Brooks, Garcia, Kerick, & Vettel, 2016) and eye movement (Liang, Reyes, & Lee, 2007). Many of these previous studies were conducted on healthy young people and more research is needed on the internal processes accompanying driving behaviour in older people.

Therefore, we wished to evaluate internal processes (perception, cognition and judgement) in older people using a DS, and in particular, to evaluate spatial navigation and eye movements. We wished to clarify whether spatial navigation was involved in lane change manoeuvres and the sight line distance distribution of the driver when he/she was approaching the intersection. To clarify the influence of each process (perception, cognition and judgement) on driving ability, we conducted a DS task with older people with no cognitive impairment and examined how environmental information influenced driving ability. Older people have poorer spatial perception and may have difficulties in extracting auditory and visual information from the surroundings (Yi, Lee, Parsons, & Falkmer, 2015). Although factors such as the direction, frequency and length of gaze affect the peripheral visual field of the older driver, it is possible that visual information processing is impaired because of further deterioration of spatial navigation abilities.

Therefore, we quantified gaze behaviours using an eye tracker and analysed the association between gaze and DS data. We examined older people's spatial navigation capabilities. Specifically, we tested participants' ability in a characteristic simulated driving scene in which oversight of the surrounding situation changes and unexpected events were likely to occur. We measured driving data and line of sight movement while driving with an eye tracker. We tested the hypothesis that there would be a gaze bias when entering an

intersection and when attempting a lane change. We compared perceptual and cognitive skills and driving behaviour in Japanese participants.

Methods

Participants

Participants were 34 healthy older Japanese adults (females: 27; males: 7; age: (mean and standard deviation (SD)) 68.2 ± 5.4 years, range: 60 to 76 years, mean number of years driver's license held: 38 years, mean driving mileage per year: 7740 ± 721.1 km) and 20 healthy young Japanese adults (females: 10; males: 10; age: 20.2 ± 5.4 years, range: 22 to 30 years, mean number of years driver's license held: five years, mean driving mileage per year: 8240 ± 935.2 km). They were healthy older and young adults living in Hiroshima Prefecture, who were voluntarily recruited through public recruitment to the present study. We explained the study details to participants in advance and collected data from those participants who provided informed consent. The inclusion criteria were: (1) without eye diseases, (2) intact physical function and limb movement ability. The exclusion criteria were as follows:

- ① Having a mental illness such as depression
- ② With a diagnosis of dementia
- ③ Difficulty in communication and cannot answer the questions during the interview
- ④ With history with motion disease and restriction, such as heart disease, disorder of brain function, etc.), and there is a danger of sudden change or deterioration in health condition during the study
- ⑤ Difficulty in following measurement during the study.

This study was approved by the Epidemiological Research Ethics Review Committee of Hiroshima University (approval number E – 1003) and conducted in compliance with the Declaration of Helsinki.

In the real world, drivers develop experience and adaptive behaviour in response to constantly changing situations. In contrast, the DS situation uses computer graphics to artificially embed landscapes and traffic events in the scenario, so the traffic scenes are restricted to several types. Therefore, although experienced drivers may be experts in a number of driving situations in the real world, in the DS driving environment used in this study, driving operation skills must be developed in a limited context. We defined experts in this study as those who had received a period of preliminary operation experience in a motion-based DS.

Neuropsychological examination

Participants completed a neuropsychological examination. We used the Benton Judgment of Line Orientation Test (BJLO) as a visual recognition evaluation battery (Benton, Hamsher, Varney, & Spreen, 1983), the Card-Placing Test (CPT) to evaluate spatial navigation (scores on Part A, Part B) (Hashimoto, Tanaka, & Nakano, 2010) and the Trail Making Test Part A and Part B (TMT-A and TMT-B) to assess visual attention and concentration (Reitan, 1958), and Raven's Colored Progressive Matrices (RCPM) to measure visual perception (Raven, 1947).

Screening assessment of driving

We used the Japanese version of the Stroke Drivers' Screening Assessment (SDSA) to evaluate driving skills to ensure that participants understand traffic rules and whether direction sense is normal. The SDSA was developed as a post-stroke screening assessment for drivers and contains four tests: (1) Dot Cancellation Test, (2) Square Matrices Directions, (3) Square Matrices Compass and (4) Road Sign Recognition Test (Lincoln & Radford, 2012). Research suggests that the SDSA is relatively successful in predicting pass/fail classification in an on-road evaluation ($p < .05$; 78.9% agreement with the principal evaluator sensitivity, 71.4%–79.3%; specificity, 77.8%), although further replication is required.

Experimental setup

DS device

The DS used in this study was a modified version of the Honda Safety Navi system, right-hand drive version (Honda Motor Co., Tokyo, Japan), a DS used for instruction in efficient, safe driving. The examinees undertook a 15-min practice session followed by 2-min \times 5 times main tests. The participants kept the driving

position and controlled the brake. The only requirement was for the examinee to brake when he or she felt it was necessary. If an examinee reported feeling simulator sickness during the practice session, further testing was immediately abandoned. The main test contained scenarios depicting such situations as coming to a stop sign, a traffic light or road hazard or a person suddenly rushing out in front of the car. We focused on two scenarios depicting oncoming right-turning cars at an intersection. We recorded the number of collisions in these two scenarios. Figure 1 shows the simulation experiment.

The control computer of the DS generates images during driving by sequentially recalculating the position, speed acceleration and other characteristics of the vehicle based on the operation of the driver. Computer graphics are used to produce a front image, a side mirror image and a rear view mirror image of the road traffic condition. A view from the driver's seat is generated and displayed as a three-dimensional moving image. It is possible to obtain data from computer-recorded input variables, such as steering, acceleration and braking and a log of output changes, such as coordinates and speed of the car body every 10 ms. For this study, we generated an urban course that contained dangerous events, such as a lane change and a bicycle crossing while turning right at an intersection. Three personal computers (PCs) were used, which were connected via an Ethernet network: a PC for graphics calculations, a PC for control and a PC for logging data input variables and output variables.

Eye tracking system

Tobii Glasses 2 (Tobii Technology, Finland, henceforth referred to as Tobii Glass, scene camera resolution: 1920×1080 ; eye camera tracking frequency: 50 Hz), which is a rapid eye movement analysis device that can record eye movement during natural



Figure 1. Experimental layout.

behaviour, was used to analyse the driver's eye movements. Raw gaze data were filtered using the Tobii I-VT fixation filter configured so that short fixations were not discarded (Olsen, 2012).

Participants wore eye Tobii Glasses, which have a one-point calibration procedure, autoparallax compensation and slippage compensation allowing for persistent calibration throughout testing with no loss of data apart from blinking. The experiment was carried out in a light-controlled room. These measures made it possible to track the line of sight movement in real time. The line of sight position was converted to monitor pixel coordinates. The eye movement data (right and left pupil diameters and visual axis coordinate values) are recorded by Tobii Glass as pixel values, and the upper left of the screen is the origin. For subsequent analysis, we transformed these data so that the centre of the screen was the origin of the viewing angle (degree). Based on the eye movement data after conversion, an area of interest (AOI) was set, and the number of gazes, the mean gaze time and the mean eye movement distance were obtained. First, we determined saccades when the speed of eye movement was 30 deg/s or more. After saccade occurrence, if the speed of eye movement was 30 deg/s or less and continued for 40 ms or longer, it was defined as gaze and the gaze time was recorded. The gaze start point is referred to as gaze point and the gaze count is the number of gaze points. As saccades occurred before the start of gaze and after gaze ended, the distance moved by the eyeball from the first saccade to the last saccade was taken as the movement distance of the eyeball.

Experimental course

We used an experimental course that simulated an urban area, as shown in Figure 1. The course

environment was set to be equivalent to a dry road surface in the daytime, and the friction on the road surface was set as $\mu=0.75$. In this urban district risk prediction course, dangerous event scenarios included oncoming cars and children jumping out in front of the car. The driving scenes shown in Figure 2 are a lane change on a straight road and a right turn scene at an intersection.

In the lane change on the straight road, the participant hears a voice instructing them to change lanes after passing the last intersection. The participant must change from the left lane to the right lane on a straight road with two lanes on one side. Figure 2 shows a right turn intersection, in which the signal ahead of the vehicle is a green light to turn from the outside lane to the outside lane, and turn right without crossing any lanes. We analysed the gaze time in each driving scene with reference to previous research (Hogan & Sternad, 2009).

Experimental procedure

Immediately before the experiment, participants completed a risk prediction practice course. The scenario in this practice course was different from the scenario used in the actual experiment. Participants completed one round of the course and the practice time was about 15 min. Older participants, however, received longer training on the DS before the experiment started. Participants subsequently attempted the set course five times (2-min \times 5 times). To control psychological state and driving operation, participants were asked to comply with the following instructions: (1) drive in compliance with the Road Traffic Act, (2) follow the voice guidance while driving and (3) when turning at an intersection, keep to the outer lane while turning.



Figure 2. Driving route.

Data analysis method

The SDSA was used to screen drivers for abilities such as sense of direction and an awareness of traffic rules. SDSA scores determined whether participants could attempt the driving task. A formula was used to predict on-road driving pass or failure. For between-group comparisons (for young and older participants) on the BJLO, CPT (part A and part B), TMT (part A and part B) and RCPM scores, two-sample t-tests were used. Test data for the neuropsychological examinations and the eye tracker AOI were correlated. We used Pearson's correlation coefficient to calculate the association between BJLO, CPT (A and B) and RCPM scores and gaze time at the intersection approach when changing lanes. To compare young and older participants on gaze data in the lane change and intersection right turn, we conducted a two-sample t-test analysis of the switching of saccades, the distance per saccade (deg/times) and saccade total distance (deg/times). We also conducted a two-way analysis of variance of the association between the driving passing point and age (older/young) using the gaze rate to AOI (mean (SD)). Process analysis was conducted to determine whether the gaze points differed according to the passing point. The data were categorised according to the four passing points for each driving scene and analysed. Within the analysis target section, the data samples were aligned at 10 cm intervals in the x direction and the position in the y direction was calculated using cubic spline interpolation. Assuming that the position data of the i sample after interpolation is $(x(i), y(i))$, passing points were set at intervals of 2 m. The passing points for the lane change were (1) before lane change 1; (2) before lane change 2; (3) lane changing; (4) after lane change (Figure 3(A)). The passing points for the right turn were (1) before entering the intersection 1; (2) before entering the intersection 2; (3) intersection entering; (4) after entering the intersection (Figure 3(B)). The significance level was set at 5%. The software used was SPSS version 17 (IBM, SPSS Inc., Chicago, USA). p Values $\leq .05$ were considered significant.

Results

Analysis of neuropsychological examination data, comparison between groups

One older participant was excluded from participation because of a predicted failure on driving performance measured by the SDSA. Table 1 shows the mean scores for each test item. Significant differences were found between the older group and the young group on BJLO ($p < .001$), CPT-B ($p < .001$), TMT-A ($p < .01$), TMT-B ($p < .001$) and RCPM scores ($p < .01$)

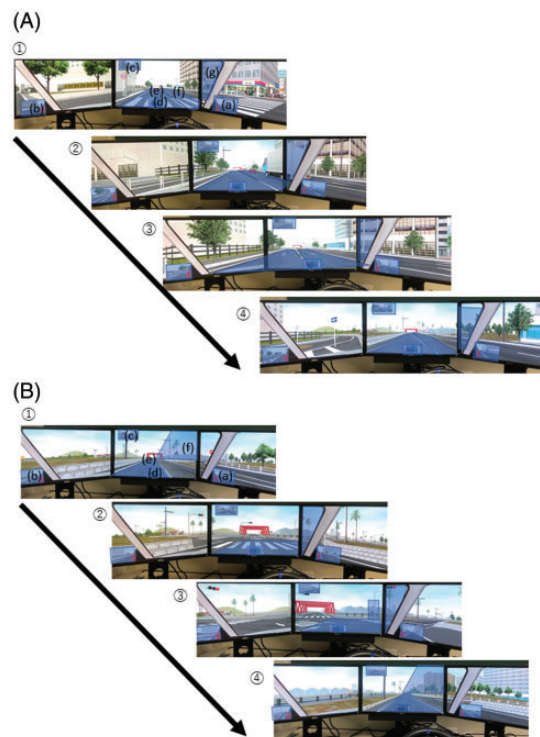


Figure 3. (A) Separate each scene during lane change. ① Before lane change 1, ② Before lane change 2, ③ Lane changing, ④ After lane change and analyse the data. The analysis target was set to AOI; (a) right door mirror, (b) left door mirror, (c) room mirror, (d) speedometer, (e) left lane, (f) right lane, (g) A-pillar. (B) Separate each scene during turn right: ① Before entering an intersection, ② before entering an intersection 2, ③ intersection entering, ④ after entering an intersection and analyse the data. The analysis target was set to AOI; (a) right door mirror, (b) left door mirror, (c) room mirror, (d) speedometer, (e) driving lane, (f) travelling direction (A-pillar).

(Table 2). The young group performed better than the older group on these examinations.

Correlation between neuropsychological examination data and eye tracking data

In the older group, a significant negative correlation was observed between gaze time and CPT-A score ($r = -0.34$, $p < .01$) and CPT-B score ($r = -0.46$, $p < .01$). There was no significant correlation between gaze time and CPT-A score ($p > .05$) or CPT-B score ($p > .05$) in the young group.

Between-group comparison of eye tracking data

There was a significant between-group difference in the switching of saccades when turning right ($p < .01$) but no significant difference in the switching of saccades in the lane change (Figure 4(b)). There was a significant difference in the distance per saccade (deg/times) in the

Table 1. Comparison between SDSA scores of older and young.

		Older (N=34)			Young (N=20)		
		Mean	SD	Range	Mean	SD	Range
Dot Cancellation Test	Time(s)	544.12	175.53	288–864	434.33	73.32	173–598
	Errors	17.9	11.32	1–39	14.9	8.2	0–10
	False	0.9	1.16	0–4	0.9	1.16	0–5
Square Matrices	Directions	25.63	4.45	16–32	29.51	2.15	24–32
	Compass	20.75	6.28	12–32	25.5	4.81	21–32
Road Sign Recognition Test		8.03	3.03	2–12	9.2	2.32	7–12

Table 2. Comparison between test scores (mean±SD) of older and young (CPT-A/B, BJLO, TMT-A/B and RCPM).

Test	Older	Young	p
BJLO	21.42±5.27	28.20±1.76	<.001
CPT-A	26.91±2.05	28.05±1.91	n.s
CPT-B	20.36±4.92	27.30±2.10	<.001
TMT-A	31.96±10.35	21.39±4.98	<.01
TMT-B	87.34±46.73	42.90±9.98	<.01
RCPM	33.67±2.10	35.00±1.35	<.01

BJLO: Benton Judgment of Line Orientation Test; CPT-A/B: the Card-Placing Test Part A and Part B; TMT-A/B: the Trail Making Test Part A and Part B; RCPM: Raven's Colored Progressive Matrices.

right turn ($p < .05$) and in the lane change ($p < .05$) (Figure 4(c) and (d)). There was a significant difference in the saccade total distance (deg/times) in the right turn ($p < .05$) and in the lane change ($p < .01$) (Figure 4(e) and (f)).

In the lane change (Figure 5), there were significant between-group differences in (a) right door mirror, (f) right lane and (g) A-pillar. For (a), there was no interaction between age and passing point ($F(4, 306) = 0.86$, $p = 0.47$) for gaze rate to AOI. A main effect was found for age ($F(1, 51) = 0.78$, $p = 0.03$) and passing point ($F(4, 306) = 111.00$, $p = 0.01$).

In the right turn (Figure 6), there were significant between-group differences in (a) right door mirror and (f) travelling direction (A-pillar). For (a), there was an interaction between age and passing point ($F(4, 306) = 0.52$, $p = 0.04$) for gaze rate to AOI. A main effect was found for age ($F(1, 51) = 0.58$, $p = 0.01$) and passing point ($F(4, 306) = 96.00$, $p = 0.02$).

Discussion

Verification of data reliability and validity

None of the study participants had any physical limitations that would have affected the implementation of the DS. One participant in the older group obtained a predicted fail on the driving screening test, and this

participant's data were excluded from analysis. For both the healthy older group and the healthy young group, the neuropsychological examination showed no objective evidence of pathological decline, and the data for the number of eye movements were judged sufficient. Therefore, the data were considered reliable. All participants received adequate training on the DS before the experiment started, which makes it likely that the data were valid.

Analysis of neuropsychological examination, comparison between groups

Data from one of the participants in the older group were excluded because of a predicted fail on the SDSA, which measures the resumption of driving ability after cerebrovascular accidents. No participants in this study had an SD value of -2 on any SDSA item and had no problems with sustained concentration or understanding the driving rules. Therefore, we judged that participants were able to attempt the DS driving task.

Significant between-group differences were found for BJLO, CPT-B, TMT (part A and part B) and RCPM scores (Table 2). Egocentric response increases with age (Surtees & Apperly, 2012). In a study of cognitive function and driving, drivers with acquired brain injuries showed performance impairment accompanied by declining frontal lobe function and participants who failed a driving test overestimated their driving performance (Lundqvist & Alinder, 2007). The results suggest that poorer self-assessment of driving ability and cognitive decline are likely to be associated, affecting driving suitability (Lundqvist & Alinder, 2007). Few of the older people in this study showed decreased frontal lobe function, but older participants scored significantly lower on attention, including visual search as evaluated by the CPT-A. It is likely that egocentric interference affects spatial recognition in older people.

Correlation between neuropsychological function and gaze time

In the older group, there was a significant negative correlation between gaze time and both CPT-A scores

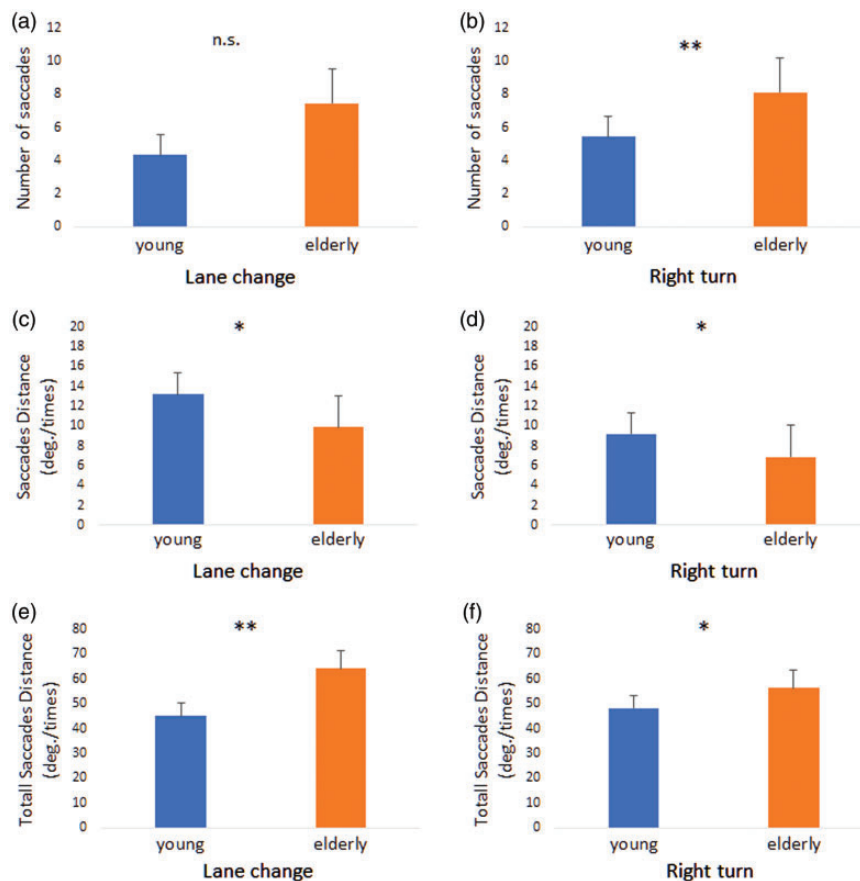


Figure 4. Comparisons of the number of saccades in lane change (a) and right turn (b). The older group took significantly higher number of saccades in right turn. Comparisons of the distance per saccade (deg./times) in lane change (c) and right turn (d). The older group took significantly shorter of the distance per saccade (deg./times) in lane change and right turn. Comparisons of the saccade's total distance (deg./times) in lane change (e) and Right turn (f). The older group took significantly longer of the saccade's total distance (deg./times) in lane change and right turn. * $p < 0.05$; ** $p < 0.01$, n.s.: not significant.

and CPT-B scores. There was no significant correlation between these variables in the young group.

These findings alone do not indicate how each of the driving skills exhibited in DS driving tasks is related to different kinds of dangerous driving behaviours in daily traffic conditions. However, a decline in spatial navigation ability and visual processing skills can impair driving skills in older people. The decline in driving ability is caused by impairment in the cognitive ability to visually attend to more than two types of information while incorporating changes in body direction, as assessed by the CPT-B.

Inter-group comparison of eye-gaze tracking data

There was a main effect for age and passing point for gaze time at the time of lane change and approach to the intersection. These results suggest that older people have poorer control of eye movement in relation to predicting the driving environment ahead, and they may show delayed responses. In the context of driving, tracking

with smooth eye movements is particularly important. The driver captures information from the dynamic driving scene. Both the fixation of the viewpoint and the smooth tracking motion may reflect how cognitive deviations prevent drivers from obtaining visual information (Liang et al., 2007). Regarding the decline of spatial navigation ability, the parietal lobe integrates sensory information from different parts of the body and is involved in the manipulation of objects and visual spatial processing. The posterior parietal lobe is further divided by the parietal groove into the parietal lobule and the inferior parietal lobule. The parietal groove and the neighbouring part of the cerebral cortex have an important role in the control of limb and eye movements. The intraparietal sulcus is divided into several areas, including the medial intraparietal area, lateral intraparietal area (LIP), ventral intraparietal area (VIP) and anterior intraparietal area. The LIP contains a two-dimensional map of the retinal coordinate system expressing the saliency of the spatial position. In addition, the VIP receives visual, somatosensory, auditory

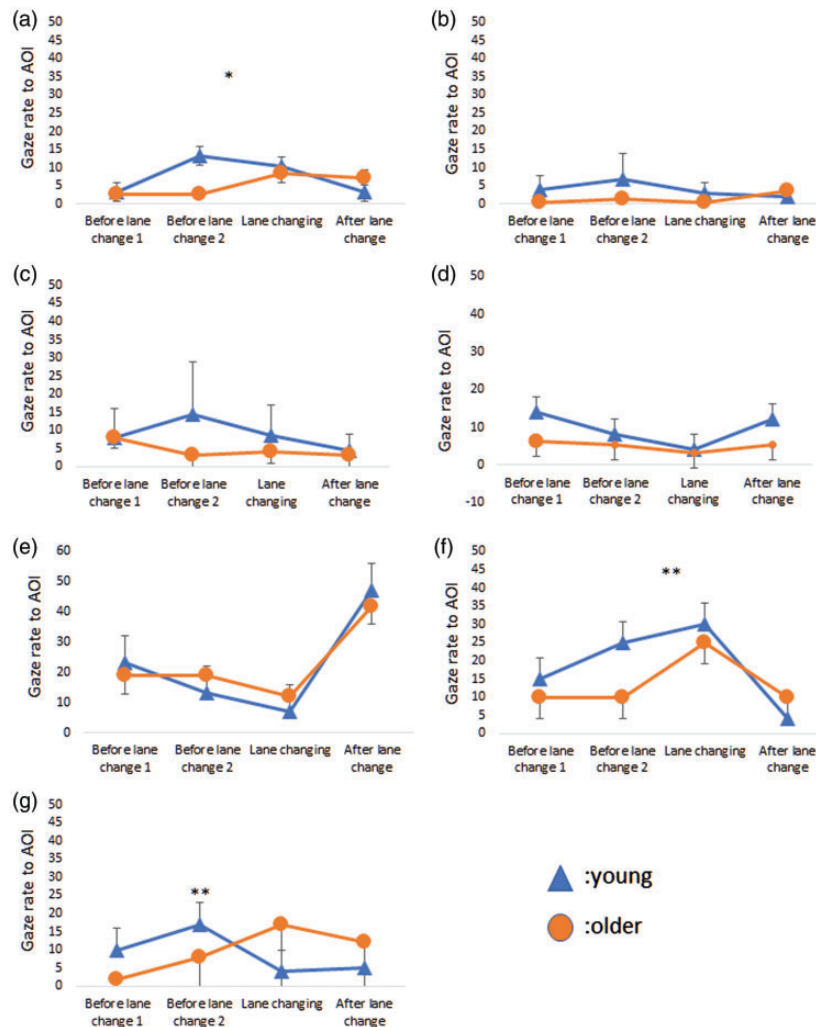


Figure 5. Association between the driving passing point (categorised as (1) before lane change 1; (2) before lane change 2; (3) lane changing; (4) after lane change) and age (older/young) using the gaze rate to AOI (mean (SD)). The AOIs were (a) right door mirror, (b) left door mirror, (c) room mirror, (d) speedometer, (e) left lane, (f) right lane, (g) A-pillar. Repeated measures two-way ANOVA: * $p < .05$; ** $p < .01$. In the lane change, significant differences were found for (a) right door mirror, (f) right lane, (g) A-pillar. (a) There was no interaction between age and passing point ($F(4, 306) = 0.86, p = 0.47$) for gaze rate to AOI. A main effect was found for age ($F(1, 51) = 0.78, p = 0.03$) and passing point ($F(4, 306) = 111.00, p = 0.01$). (f) There was no interaction between age and passing point ($F(4, 306) = 0.86, p = 0.30$) for gaze rate to AOI. A main effect was found for age ($F(1, 51) = 0.88, p = 0.02$) and passing point ($F(4, 306) = 103.00, p = 0.01$). (g) There was an interaction between age and passing point ($F(4, 306) = 0.16, p = 0.03$) for gaze rate to AOI. A main effect was found for age ($F(1, 51) = 0.92, p = 0.02$) and passing point ($F(4, 306) = 99.00, p = 0.01$).

and vestibular input and integrates this information; the activation of neurons by visual stimulation is related to movement planning. In drivers that have good steering function, prediction, recognition and steering operations that reduce deviations from the path are sufficient to maintain a stable operating state. We found that older drivers had a longer gaze time, suggesting that these abilities are impaired.

Drivers are required to perform various driving behaviours according to the traffic conditions. Hierarchical models of the driver are useful for understanding the components of driving behaviour. We refer to a

hierarchical model of driving behaviour that combines the driving behaviour model of the driving behaviour model of Michon and Rasmussen's model, which comprises three categories of driving behaviour (Rasmussen, 1983; Michon, 1985). According to this model, the task of driving a car is influenced by an automated operation process and the driver's driving experience. In other words, gaze behaviour reflects differences in gaze strategies arising from changes in spatial navigation capability during the driving operation process.

The results for the intersection right turn suggest that the older group gazed closely at the speedometer

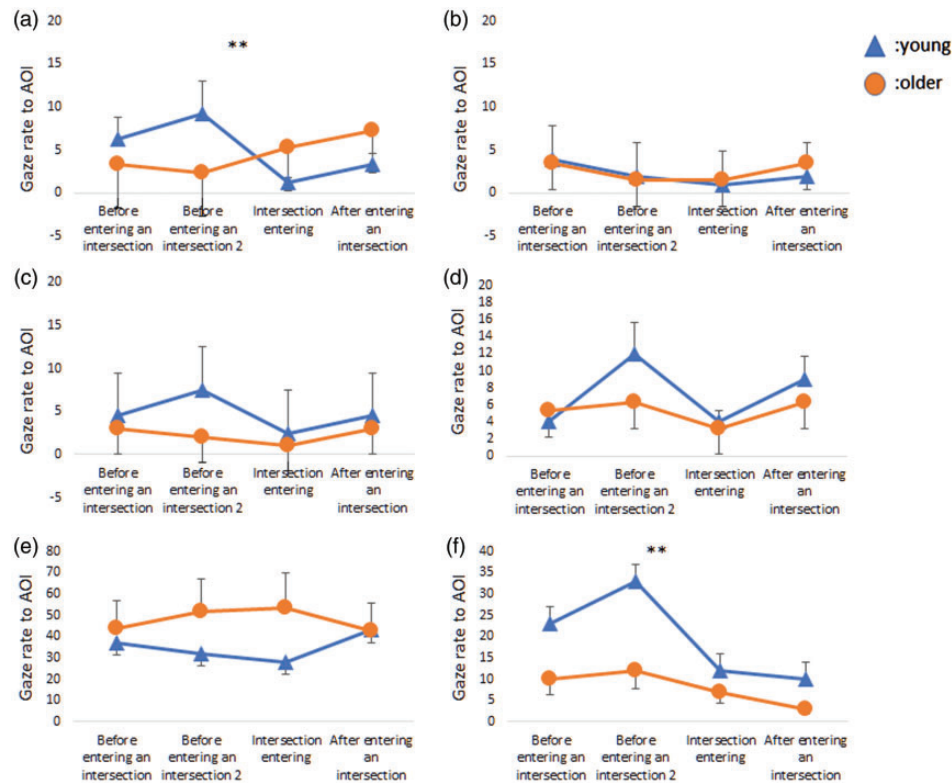


Figure 6. Association between the driving passing point (categorised as (1) before entering the intersection 1; (2) before entering the intersection 2; (3) intersection entering; (4) after entering the intersection and age (older/young) using the gaze rate to AOI (mean (SD)). The AOIs were (a) right door mirror, (b) left door mirror, (c) room mirror, (d) speedometer, (e) driving lane, (f) travelling direction (A-pillar). Repeated measures two-way ANOVA: * $p < .05$; ** $p < .01$. In the right turn, significant differences were found for (a) right door mirror, (f) travelling direction (A-pillar). (a) There was an interaction between age and passing point ($F(4, 306) = 0.52$, $p = 0.04$) for gaze rate to AOI. A main effect was found for age ($F(1, 51) = 0.58$, $p = 0.01$) and passing point ($F(4, 306) = 96.00$, $p = 0.02$). (f) There was no interaction between age and passing point ($F(4, 306) = 0.86$, $p = 0.20$) for gaze rate to AOI. A main effect was found for age ($F(1, 51) = 0.82$, $p = 0.02$) and passing point ($F(4, 306) = 116.00$, $p = 0.01$).

in an attempt to obtain information about the above-mentioned vehicle control. If viewpoint acquisition density decreases with age, older participants will perform more poorly in a spatial viewpoint acquisition task (Herman & Coyne, 1980). Steering and prediction of future vehicle position are related to the deviation from the road ahead (Calhoun, et al., 2002). Older people have poorer control of eye movements during driving. When driving in a dangerous situation, older drivers narrow the visual search area by reducing the size of saccadic eye movements, which allows more visual information to be collected by increasing gaze fixation time. This compensatory response occurs because older drivers have poorer spatial cognition.

Study limitations and future research

One of the study limitations was that we used only DS data on driving ability, and did not measure physiological behaviour, visual sensitivity and self-reported driving ability. Future strategies for driver education

should simultaneously measure muscle activity, brain activity and at the time of DS implementation, and analyse the associations between these different types of data.

Conclusion

We aimed to clarify differences in spatial navigation ability in driving behaviour in healthy older people and healthy young people using a DS. There was a significant correlation between eye movement during DS implementation and spatial navigation ability, and significant differences between young and older people in gaze time. Our study also explored a possible evaluation index of driving ability that can be used to quantify driving performance, thus helping drivers to improve their driving performance. The findings of this study might be used for driving evaluation by taking data of CPT at the clinical site. It is suggested that self-centred space precaution which automatically processes information with egocentric space perception is

increased in older; this finding will be useful for drivers' guidance by training their allocentric reference frame.

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