Age-Related Differences of Cognitive Functions when Encountering Driving Hazards on Expressways

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***Abstract* - For this study, we defined four situations that are likely to trigger accidents on highways as driving hazards: vehicle breakdowns, sudden appearance of small animals, falling objects, and lane decreases. Carrying out running experiments while controlling the time of day (daytime or nighttime) and traffic flow (presence or absence of overtaking vehicle), we conducted a comparison for each driving topic, particularly addressing driving characteristics of young drivers and elderly drivers related to "cognition", "judgment", and "operations". Using evaluation experiment results, we strove to analyze the driving characteristics of elderly drivers for driving hazards encountered on highways based on comparison to those of young drivers. Results revealed findings unique to elderly drivers for response after "cognition" and reaction times necessary for "judgment and operations".**

Keywords – driving behavior; driving topic; elderly drivers; highway; human engineering

I. INTRODUCTION

Although the annual numbers of deaths caused by traffic accidents in Japan show a downward trend, traffic accidents caused by erroneous operations by elderly drivers and reverse running on highways have become particularly problematic in recent years. Traffic accidents caused by elderly drivers are frequent and entail a high risk of severe injury. Therefore, countermeasures must be taken to cope with Japan's impending super aging society.

As factors contributing to traffic accidents by elderly drivers, there might be common points among elderly people such as slowed driving operations related to cognition, judgment, and operations, mistaken operations of handles and brakes because of the distribution of attention to multiple tasks and concentration, and momentary carelessness and distraction. Recently, various traffic accident preventive safety systems have been studied, as represented by automatic driving efforts. Practical application of these systems has been accelerating. However, most such systems merely collect and analyze external information of the vehicle. Such systems cannot deal adaptively with the driving characteristics of individual drivers. Furthermore, preventive safety technologies based on some standard general driver make it difficult to address the slowing of driving behaviors that are peculiar to elderly people, related to recognition, judgment, and operations. Approaches must be made for preventive safety systems dedicated to the driving characteristics of elderly drivers.

Our earlier study [1] examined four driving situations as driving hazards that are likely to trigger accidents: vehicle breakdowns on the road shoulder, sudden appearance of small animals, falling objects, and lane decreases. Those situations are especially dangerous for highways: they have high mortality rates and easily lead to severe accidents. We conducted running experiments while controlling the time of day (daytime or nighttime) and traffic flow (with and without overtaking vehicles). Specifically, we devoted attention to a series of driving behaviors related to cognition, judgment, and operations for the respective driving topics. We compared and analyzed the driving characteristics of young drivers and elderly drivers. Results clarified that elderly drivers had longer reaction times than young drivers. Particularly, the reaction time associated with "cognition" was remarkable. However, we have not validated the findings. The running scenarios were limited for analyses in terms of the time of day (daytime) and the traffic flow (no overtaking vehicle), with few elderly driver participants.

This study clarifies the driving characteristics of elderly drivers for these driving hazards by increasing the number of elderly driver participants and performing comparison with data of young drivers, examining influences of visibility because of changes in the time of day (daytime / nighttime) and changes in the surrounding cognitive situation because of the presence or absence of overtaking vehicles.

This paper is presented as follows. We review related work to clarify the position of this study among existing studies of the literature in Section II. Section III presents a definition of the experiment protocols, driving topics, and running scenarios. In Section IV, we examine the correspondence relation between measurement points of driver reaction and eye-gaze information, particularly addressing the reaction time necessary for each action, i.e., cognition, judgment, and operations for driving topics. Additionally, we compare the average reaction times of all drivers, elderly drivers, and young drivers at each measurement point for "falling objects", which is one of the driving topics. Finally, we present conclusions and intentions for future work in Section V.

II. Related Works

Causes of fatal accidents involving are mostly unsuitable driving operations and are attributed to physical characteristics, psychological characteristics, driving characteristics, and social characteristics of the elderly drivers themselves. Physical characteristics indicate declining physical function such as vision and exertion ability. Assistive technologies and systems can reduce the operation load imposed by steering. Some systems automatically reduce the speed and mitigate damage when a possibility of a collision arises. Many systems have been put into practical use [2]. Psychological characteristics of elderly drivers render them as less able at parallel processing of multiple streams of information. They tend to become self-oriented. Driving characteristics show a mismatch of consciousness and behaviors caused by feeling overly "accustomed" to driving or relying on skills of "driving that would be" based on past experiences. Additionally, social characteristics imply differences in characteristics by generations, such as a decline in communication skills and the influence of automation [3]. As solutions to these characteristics which might impede elderly drivers, the following have been reported. It is possible to reform consciousness and motivate people for safe driving by having each elderly person participate in efforts for traffic safety by their own will rather than passively [3]. Elderly drivers are able to improve their attention abilities by pointing and designating signs to recognize [4].

Recent studies examining elderly drivers have been specifically undertaken by the Nagoya COI project, which was adopted by the Ministry of Education, Culture, Sports, Science and Technology as an innovative creation program [5]. It has pursued the construction of a human aging driving characteristics database (Dahlia) promoted as part of this project, with cognitive function tests, driving aptitude tests, visual function tests, driving characteristics surveys, etc. They have been conducted for 300 elderly people each year [6]. The project collects and analyzes actual road driving data from a drive recorder and driving test data from a driving simulator. The results clarify correlation between cognitive and visual functions of elderly people and collision rates [7]. Additionally, a driver agent system was developed to encourage and improve elderly drivers' good driving behavior [8] [9]. Experiments were conducted to evaluate the acceptability of the system. Results demonstrated the effectiveness of repeatedly experiencing video feedback [10] [11].

Furthermore, Takahara et al. [12] analyzed the characteristics at a temporary stop location to study the cognitive function of elderly drivers. Results demonstrated the effectiveness of their system through development of a voice guidance type temporary stop support system. Iida et al. [13] assessed a hypothesis of reverse running processes as an example of elderly drivers' accidents on an expressway. They confirmed that the psychological state of the elderly driver and the road composition make reverse running occur easily.

Abe et al. [14] constructed a driving simulator experiment to investigate driving condition and traffic environment effects on visual behavior. Specifically, they examined how a visual field is influenced as a function of cognitive distraction. They simulated cognitive distraction by an experimental secondary task related to mental calculations. Their results indicated that a driver's reaction time to a target mark was increased as a result of cognitive distraction. Honma et al. [15] examined how drivers' visual attention is influenced when a driver is drowsy. They used the knowledge to assess driver impairment related to object recognition. Driving simulator experiment results showed that drowsy driving impaired drivers' visual attention, particularly on conditions with no vehicle ahead, compared to normal driving.

For research and development of Autonomous Driving Systems (i.e., Strategic Innovation Creation Program: SIP), which have recently attracted much attention, legal systems and infrastructure developments have been promoted to realize automatic driving on expressways and autonomous automatic driving in restricted areas [16]. Wada et al. [17] compared and verified perceptions of elderly drivers and general drivers on the expressway during autonomous driving based on SAE level 2 [18]. As in their earlier studies, results of analyzing characteristics of elderly drivers using a semi-autonomous vehicle (i.e., pro-pilot) of SAE Level 2 confirmed that peripheral cognitive levels decrease [19] [20].

Nevertheless, these studies have not particularly analyzed situations (driving topics or hazards) that readily induce accidents on highways, such as vehicle breakdowns on the road shoulder, sudden movements of small animals onto the roadway, falling objects, and reduced lanes during maintenance work. This study used driving experiments with controlled time of day and traffic flow to analyze driving behaviors related to cognition, judgment, and operations of these driving topics. Results clarify the elderly drivers' driving characteristics.

III. Methods

This section defines the experiment protocols and four driving hazards that are likely to cause accidents. Next, we present running scenarios with controlled daytime or nighttime, and presence or absence of an overtaking vehicle.

A. *Experiment Systems*

Although many people perform driving behaviors every day, many difficulties arise in clarifying individual driving characteristics from actual behaviors on the road in real environments. Driving behaviors vary depending on the road environment and traffic conditions prevailing at the time. Actual road conditions cannot be reproduced constantly. If any behavior varies, distinguishing clearly whether the variation is caused by a difference in traffic conditions or by variation among individuals is not possible.

This study used a driving simulator (DS) to assess driving behaviors for freely set road environments and traffic conditions affecting driver behaviors. Figure 1 portrays the experiment system configured to measure driver behaviors. The DS used for experiments has platforms corresponding to compact and six-axis motion, which is equipped with ordinary cars. The DS has three-color liquid-crystal displays mounted at the cabin front. It also has a function reproducing pseudo-driving environments that are freely configurable to horizontal viewing angles. Figure 1 shows cameras installed to the left and right and center of the three-color liquid-crystal monitors mounted at the cabin front. Without restraining drivers, they gather body information such as head poses, face orientations, and eye-gaze movements. Additionally, we set an infrared pod on top of the instruments at the cabin front. The camera heads and infrared pod are input-based sensors of a head-gaze tracking device (FaceLAB; Ekstreme Machine Corp.). Through preliminary test runs with multiple subjects, we confirmed that the stereo camera head and the infrared pod installation do not interfere with visibility during driving. To capture driver facial expressions, a USB camera (Xtion pro Live; ASUS Corp.) was installed at the top of the liquid crystal monitor at the center of the cabin front.

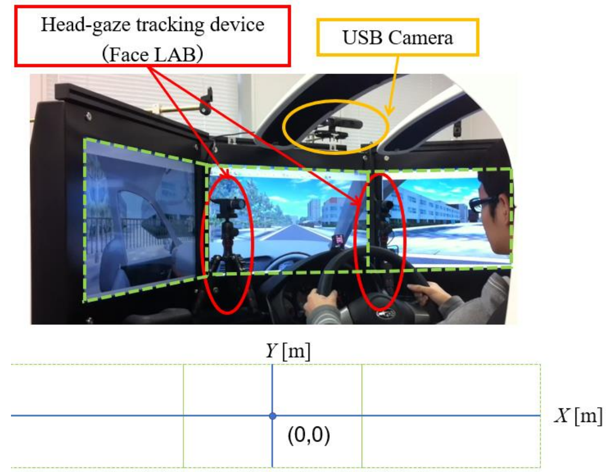


Figure 1. Experiment system for measuring driver behaviors.

B. *Experiment Protocols*

Figure 2 presents the experiment protocol outline. Initially, as individual characteristics of each subject, we conducted an examination of the following questionnaire methods using the driving style check sheet: attitude, orientation, and concept to work on driving [21]. The operation burdens were imposed using a driving load sensitivity check sheet [22]. For one running test, each target subject wore a heart rate monitor (RS800CX; Polar). We measured the instantaneous heart rate during a normal state at 1 min in advance. Next, to improve the measurement accuracy for face orientation and eye-gaze movements of each participant, we calibrated the cameras for use with a head-gaze tracking device (FaceLAB). We recorded a video of the driver's face while driving with the USB camera (Xtion Pro Live; ASUS Corp.) to analyze the driver facial expressions. After these preparations, each participant ran along the four running scenarios described in Section III.C by synchronizing the time bases of all measuring devices. Finally, a questionnaire specifically asking about the driving hazards given at random, subjective reviews, a four-stage check was administered when a driving hazard occurred. After obtaining approval of the Akita Prefectural University Research Ethics Board, the experiment contents were explained completely to participants, after which we obtained written consent from participants. We also obtained their agreement to publish their face images. Participants were 26 people: 10 young drivers (avg. 22 years old) and 16 elderly drivers (avg. 64 years old).

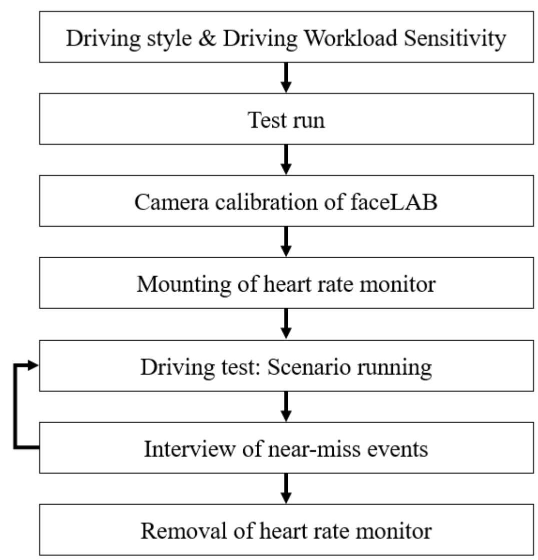
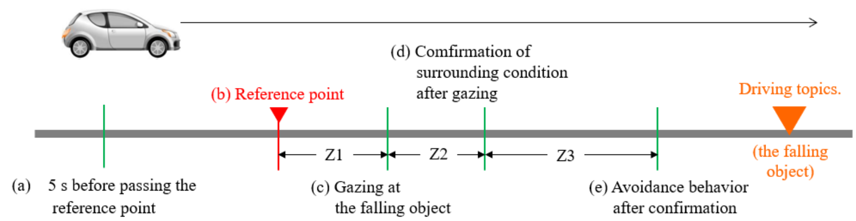


Figure 2. Outline of experiment protocols.

C. *Driving hazards and Running scenarios*

The driving course used for the experiment is a straight course of two lanes with no lane changes on one side simulating the Tohoku Expressway. The course starts running from the driving scene, which converges from the acceleration lane to the expressway. Driving hazards in one



	(a)	(b)	(c)	(d)	(e)
Velocity	101 km/h	100 km/h	98 km/h	98 km/h	96 km/h
Time(Video)	1:47.67	1:52.65	1:55.93	1:56.26	1:58.63

Z1 3.28 s
Z2 0.33 s
Z3 2.37 s

Figure 3. Measurement points of driver reaction to driving topics.

run were set randomly. Measurement points of each driver's reaction for each driving hazard are shown in Figure 3. Figure 4 presents the state of each driving hazard. The falling object in Figure 4(a) is installed at the center of the left lane. It interferes with the running course. The sudden appearance of small animals shown in Figure 4(b) was set so that when the vehicle passed the fixed point, it emerged from the front left side of the vehicle and traversed to the right to close the driving path of the vehicle. The broken down vehicle in Figure 4(c) represented a large truck parked on the shoulder because of a failure. Because of the lane decrease in Figure 4(d), the overtaking lane is unavailable because of maintenance. Lanes decrease from two lanes to one lane. For cases in which a driving hazard and the vehicle come into contact, "collision" was displayed on the front screen, but running experiments continued.

Next, we present an overview of running scenarios. To incorporate consideration of differences in visibility because of the time of day, we set the two conditions of daytime and nighttime, as well as the presence or absence of an overtaking vehicle as traveling conditions when encountering each driving hazard. Figure 5 presents driving scenarios of four types with control of the time of day (i.e., daytime or nighttime) and traffic flow (i.e., presence or absence of overtaking vehicles). The orders of occurrence of each driving topic were of two patterns: type A (i.e., falling objects → sudden appearance of small animals → breakdown vehicles → lane decrease) and type B (i.e., breakdown vehicles → sudden appearance of small animals → falling objects → lane decrease). The running time for one scenario is about 7–10 min. We gave instructions to each driver to observe the speed limit of 100 (km/h). Additionally, the maximum speed was limited automatically to 120 (km/h) on the DS side.

IV. Experiment Results and Arguments

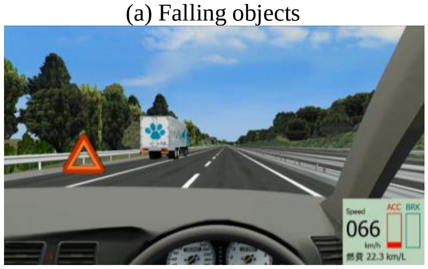
Based on safety confirmation behaviors related to the driving hazards, we analyzed the reaction times of all drivers, elderly drivers, and young drivers at each measurement point. Finally, we assessed differences of driving characteristics between elderly drivers and young drivers, particularly addressing cognition, judgment, and operation. We will further develop the analysis of an earlier study [1] based on the influence of visibility because of changes in the driving time of day (daytime / nighttime) and changes in the perception of surroundings because of the presence or absence of overtaking vehicles. Specifically addressing the reaction time related to cognition, and that related to judgment and operation, we compare and analyze the respective driving characteristics of elderly drivers and young drivers.

A. Measurement points and driver response to driving hazards

Specifically examining eye-gaze behaviors for these driving topics and safety confirmation behaviors related to lane change, we assess the correspondence between measurement points of driver reaction and eye-gaze information (i.e., heat maps, saccades) as portrayed in Figure 3. Figure 6 presents the time series changes of heat maps and saccades corresponding to each measurement point for the falling object. Each heat map represents the degree of gaze concentration in each of the following sections. They are from b) passing the reference point to c) falling object gazing, from c) falling object gazing to d) checking surrounding conditions, from d) checking surrounding conditions to e)


(a) Falling objects


(b) Sudden appearance of small animals


(c) Vehicle breakdown


(d) Lane decrease during work

Figure 4. Driving topics for running test.


(a) Sunny daytime; no overtaking vehicles


(b) Sunny daytime; overtaking vehicles


(c) Sunny nighttime; no overtaking vehicles


(d) Sunny nighttime; overtaking vehicles

Figure 5. Running scenarios.

avoidance actions. In addition, the time series changes of saccades are divided into two sections: from a) 5 s before passing the reference point to b) passing the reference point, and from b) passing from the reference point to e) avoidance action. Specifically examining the time series changes of heat maps and saccades in Figure 6, we can confirm driver states related to the attention to the falling object and the surrounding situation confirmation because of lane change. Consequently, based on the vehicle speed of b) the reference point during the passage, one can estimate the *reaction* time required for each action: the cognition, judgment, and operation for the falling object.

B. *Driver Response to Falling Objects*

Figure 7 presents the respective average reaction times of all drivers, elderly drivers, and young drivers at each measurement point for "falling objects" which is one driving topic. In Figure 7, the respective reaction times are shown.

1) from b) passing the reference point to c) falling object gazing,
2) from c) falling object gazing to d) surrounding situation confirmation,
3) from d) surrounding situation confirmation to e) avoidance behavior

Results for driving behaviors related to cognition, judgment, and operations for falling objects show that the elderly drivers tended to have longer reaction times than young drivers.

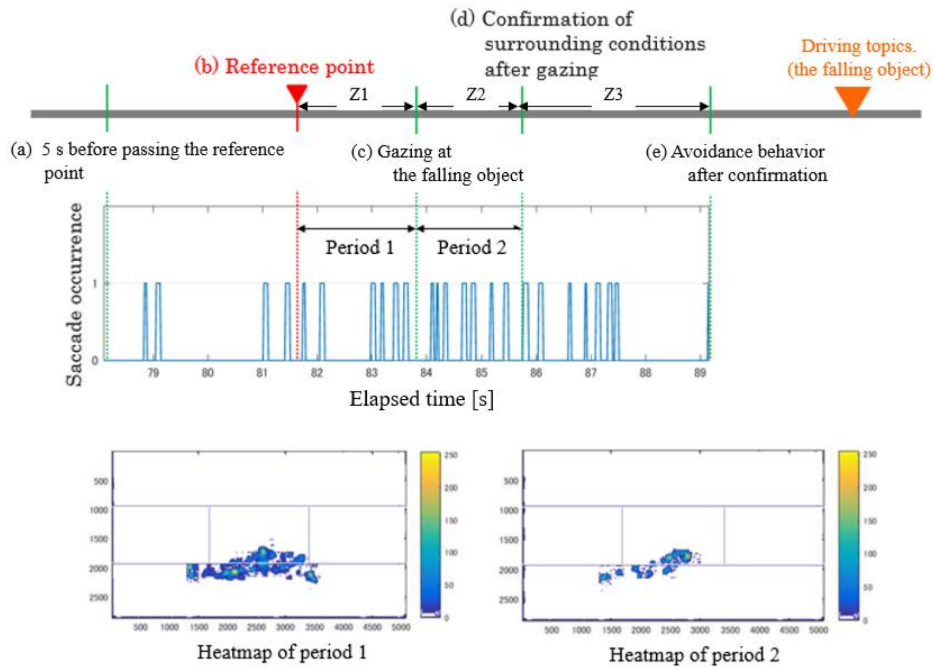


Figure 6. Time series changes of heatmaps and saccades corresponding to respective measurement points.

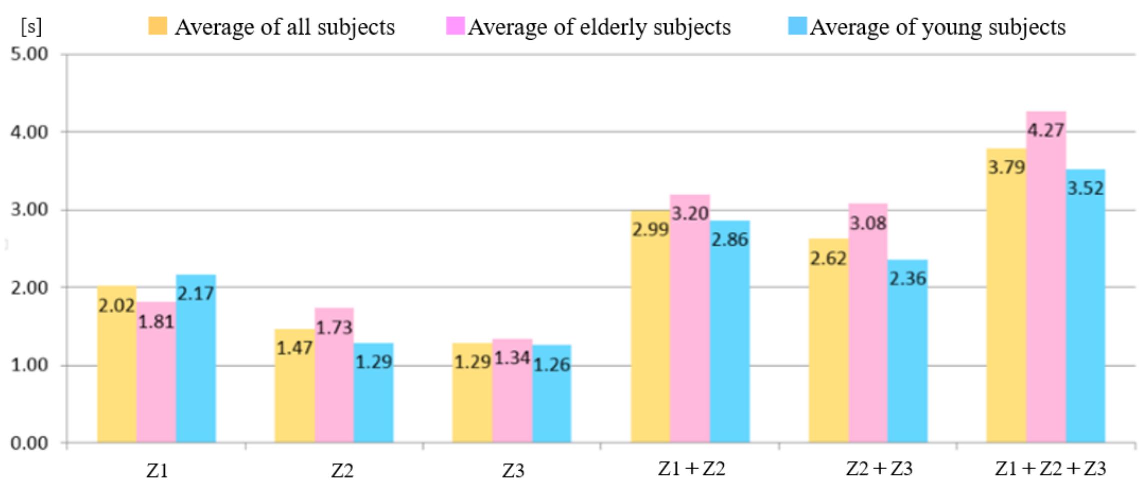


Figure 7. Driver reaction time to falling objects.

Furthermore, by classifying drivers based on the average of all participants and devoting attention to the relation with the driving style, we analyzed the existence of the following four groups.

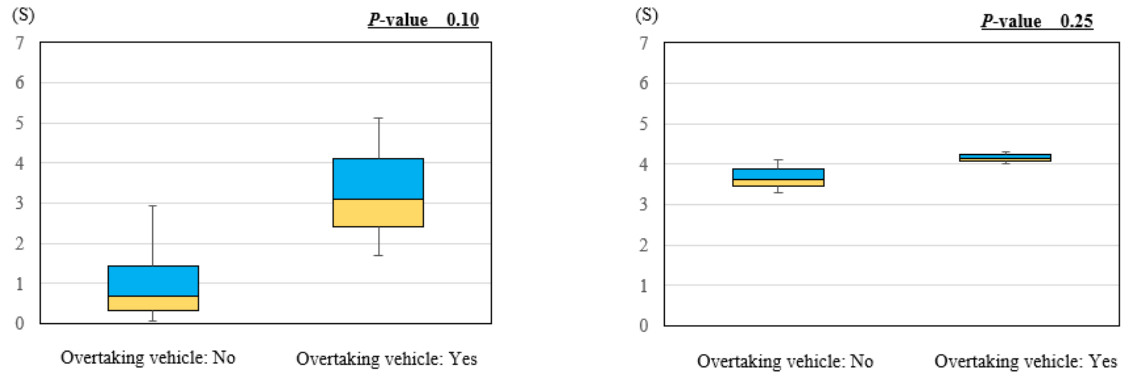
· Group A: Discovery and situation confirmation are quick; allowance for operation (i.e., cognition, judgment, and operation are all fast)

· Group B: Discovery is late, but situation confirmation and handling are quick (i.e., cognition is slow, but judgment and operation are fast)

· Group C: Discovery and situation confirmation are slow; operation is gradual (i.e., cognition, judgment, and operation are gradual)

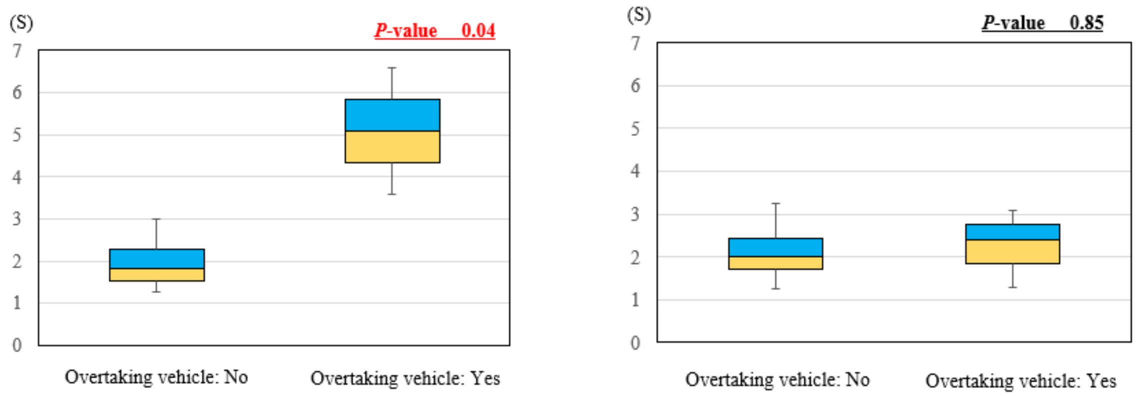
· Group D: All reactions are average (i.e., cognition, judgment, and operation are all average)

Young drivers were classified into Group A or Group D, whereas the elderly drivers were more likely to be classified as Group B or Group C. We infer that driving behavior characteristics shift from group B to group C as drivers age.



(a) Young drivers (b) Elderly drivers

Figure 8. Response time for "cognitions" during daytime.



(a) Young drivers (b) Elderly drivers

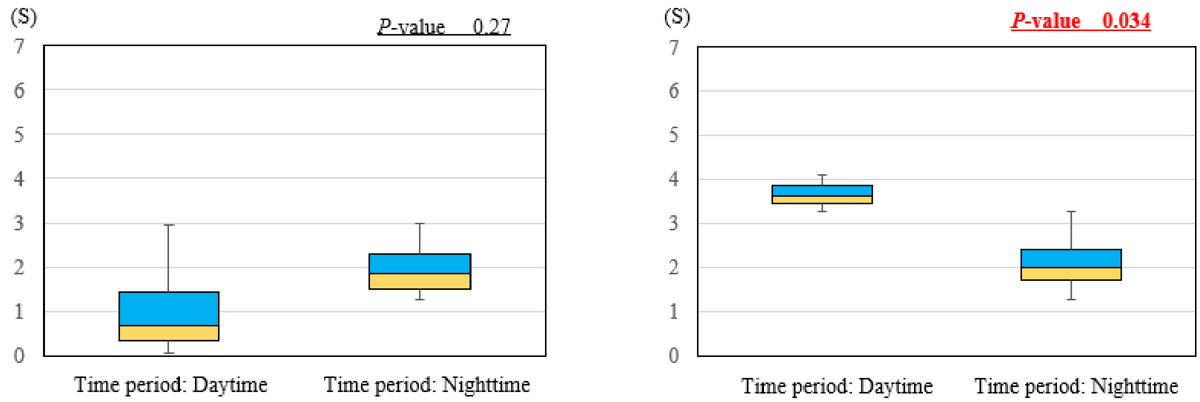
Figure 9. Response time for "cognitions" during nighttime.

C. *Driver Response to Cognition*

We next analyze driver reaction times for "cognition" from the viewpoint of surrounding recognition because of the presence or absence of overtaking vehicles. Figure 8 presents the reaction time of "cognition" during daytime. Figure 9 depicts the reaction time of "cognition" during nighttime. In these figures, panel (a) shows results for young drivers; panel (b) shows result for elderly drivers, clarifying differences of reaction time related to the presence or absence of overtaking vehicles. Particularly for young drivers in Figure 8 and Figure 9, the reaction time of "Overtaking vehicle: Yes" is longer than that of "Overtaking vehicle: No" for both daytime and nighttime. Especially, in "Time period: Nighttime", a significant difference (p = 0.04) was found. As a general characteristic, we can confirm that the reaction time tends to be longer at night with poor visibility. However, for elderly drivers, differences of the reaction time depending on the presence or absence of the overtaking vehicle are only slightly noticed. The reaction time of nighttime tends to be shorter than that of daytime.

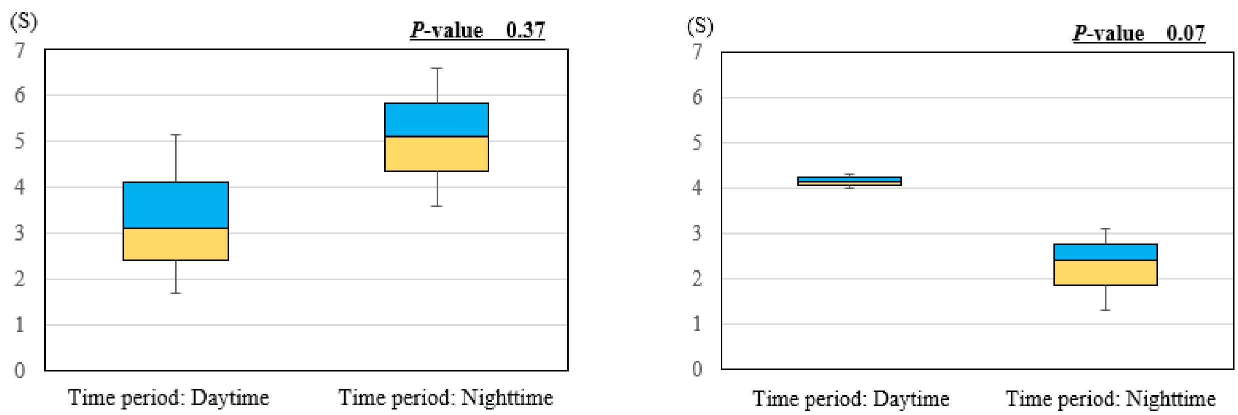
Next, we attempt to analyze visibility because of differences of the driving time of day (i.e., daytime and nighttime). Figure 10 presents the reaction time of "cognition" for "Overtaking vehicle: No". Figure 11 shows the reaction time of "cognition" for "Overtaking vehicle: Yes". In these figures, panel (a) shows results for young drivers; panel (b) presents results for elderly drivers. Specifically examining the elderly drivers in Figures 10 and 11, the response time of "Time period: Nighttime" is shorter than that of "Time period: Daytime", irrespective of the presence or absence of overtaking vehicles. A significant difference (p = 0.034) was found. By contrast, for young drivers, the difference of the reaction time between daytime and nighttime is slight, but reaction times of "Overtaking vehicle: Yes" tend to be longer than those of "Overtaking vehicle: No"

Based on the results described above, after summarizing conditions related to daytime and nighttime, and the presence or absence of overtaking vehicles, we analyze the reaction times and the moving distances required for "cognition" while comparing the elderly drivers to the young drivers.



(a) Young drivers (b) Elderly drivers

Figure 10. Response time for "cognitions" in "Overtaking vehicle: No".



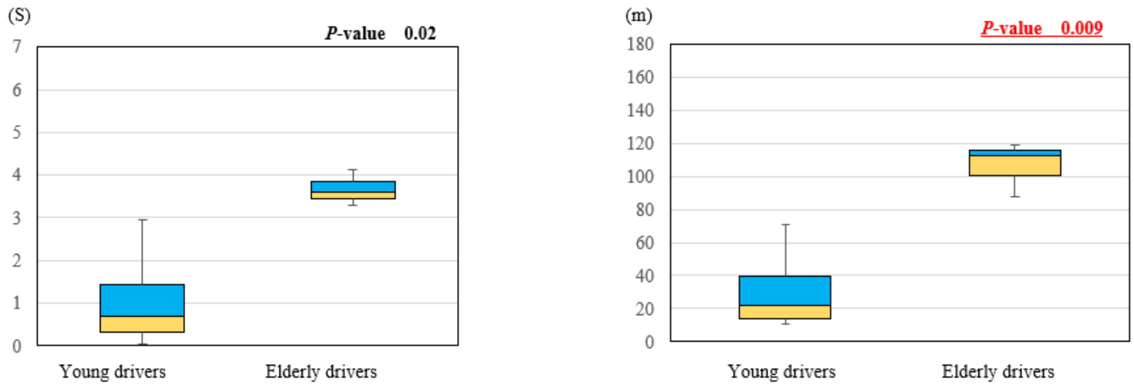
(a) Young drivers (b) Elderly drivers

Figure 11. Response time for "cognitions" in "Overtaking vehicle: Yes".

Figure 12 presents results obtained for "Time period: Daytime" and "Overtaking vehicle: No". Figure 13 presents results for "Time period: Nighttime" and "Overtaking vehicle: Yes". In these figures, panel (a) shows the reaction times of "cognition"; panel (b) shows the moving distance necessary for recognition, indicating the difference between elderly drivers and young drivers. By analyzing the results depicted in Figure 12, we can confirm that the reaction time and the moving distance of elderly drivers are longer than those of the young drivers. Especially, a significant difference (p = 0.09) in the moving distance was found. Actually, the tendency is reversed for results of Figure 13. The reaction time and the moving distance of the elderly drivers are shorter than those of the young drivers. Specifically examining the young drivers in Figures 12 and 13, one can confirm that the reaction time and the moving distance during nighttime are longer than those during daytime. Generally, visibility during nighttime is regarded as worse. Therefore, the results of young drivers are valid. However, the results obtained for elderly drivers in Figures 12 and 13 did not reflect the same tendency. The reaction time and the moving distance during nighttime were shorter than those during daytime. According to the questionnaire survey after the running test, the majority accounted for the elderly drivers as "the nighttime course made it easier to recognize falling objects". The reason for this trend might be that eye-gaze targets were limited during nighttime driving.

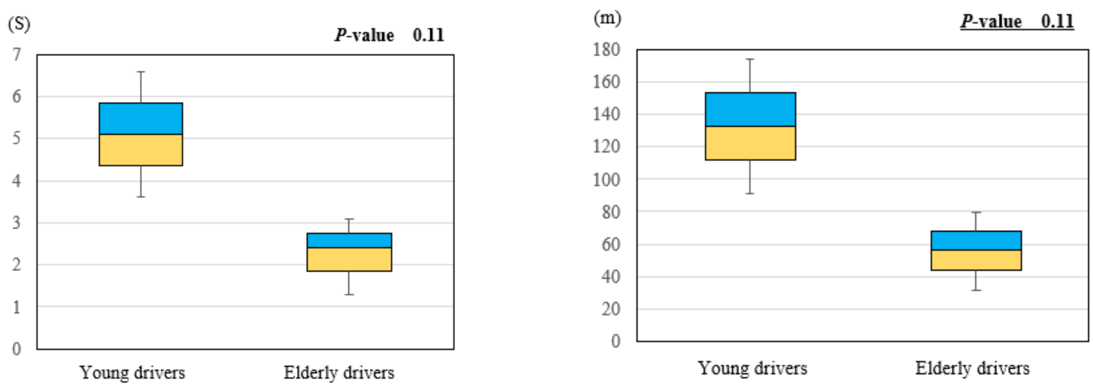
D. Driver Response to Judgment and Operation

We attempt to analyze the driver reaction time for "judgment and operation" from the viewpoint of recognition of the surroundings because of the presence or absence of overtaking vehicles. Figure 14 presents the reaction time of "judgment and operation" for daytime. Figure 15 portrays the reaction time of "judgment and operation" during nighttime. In these figures, panel (a) shows the results obtained for young drivers; panel (b) shows result obtained for elderly drivers, clarifying difference of reaction times related to the presence or absence of overtaking vehicles. Specifically examining the young drivers in Figures 14 and 15,



(a) Response time for "cognitions" (b) Moved distance for "cognitions"

Figure 12. Response time and moved distance for "cognitions" in "Time period: Daytime" and "Overtaking vehicle: No".



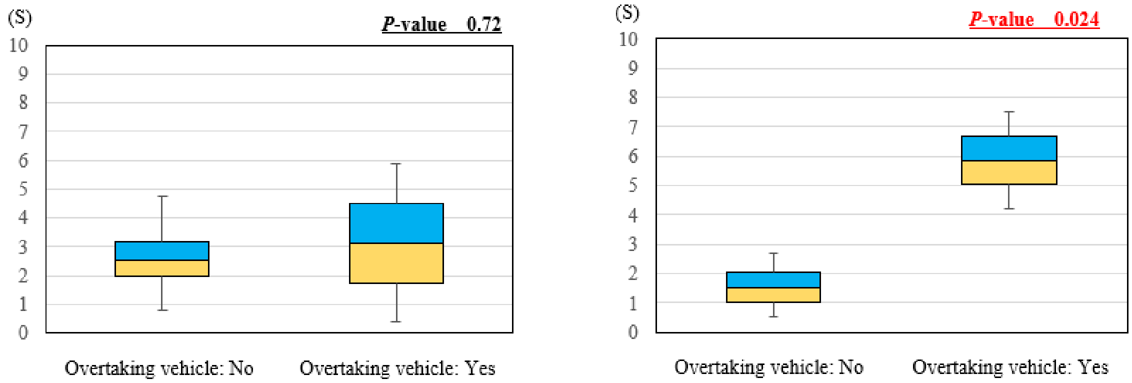
(a) Response time for "cognitions" (b) Moved distance for "cognitions"

Figure 13. Response time and moved distance for "cognitions" in "Time period: Nighttime" and "Overtaking vehicle: Yes".

differences of the reaction time depending on the presence or absence of the overtaking vehicle is noticed only slightly during daytime. However, the reaction time of "Overtaking vehicle: Yes" is longer than that of "Overtaking vehicle: No" during nighttime. A significant difference (p = 0.007) was found. However, for elderly drivers, the reaction time of "Overtaking vehicle: Yes" is longer than that of "Overtaking vehicle: No" during daytime. A significant difference (p = 0.024) was found. However, the difference of the reaction time related to the presence or absence of the overtaking vehicle is noticed only slightly at nighttime. Additionally, we can confirm that the reaction time of daytime tends to be shorter than that of nighttime.

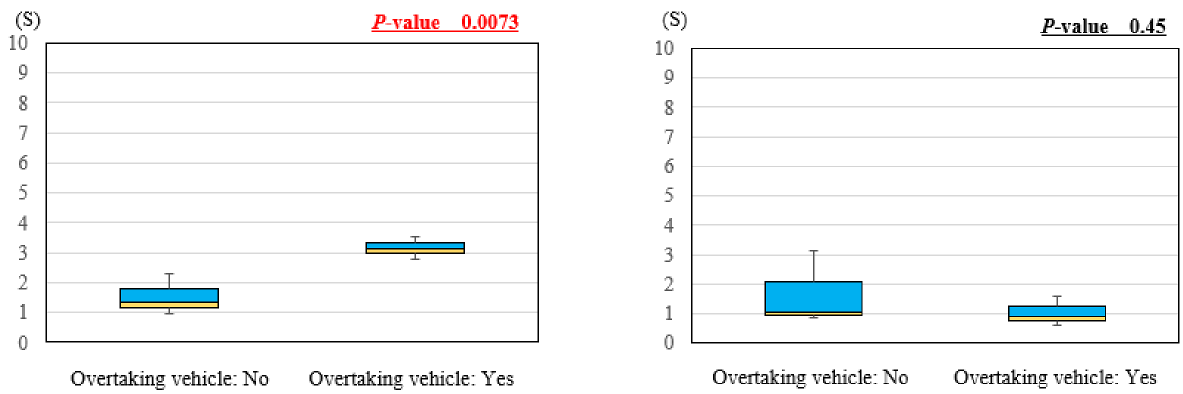
Next, we particularly address the environment in which the driving conditions are the most severe for each driver (i.e., "Time period: Nighttime" and "Overtaking vehicle: Yes"). Thereby, we attempt to analyze the response time for "judgment and operation" and their necessary moving distance by comparing elderly drivers to young drivers. Figure 16 presents the result for "Time period: Nighttime" and "Overtaking vehicle: Yes". In the figure, panel (a) shows the response time of "judgment and operation"; panel (b) shows the moving distance required for them. It shows the difference between elderly drivers and young drivers. The response time and moving distance of the elderly drivers are shorter than those of the young drivers. Particularly for the moving distance, a significant difference (p = 0.012) was found. The elderly drivers have more driving experience than the young drivers. We infer that the difference in driving behaviors related to "judgment and operation" after recognition resulted from their differences in driving experience.

Finally, to evaluate the state of peripheral recognition for each driver quantitatively, we specifically examine the number of saccades caused by differences in the driving time of day (i.e., daytime or nighttime), and compare data obtained for the elderly drivers and the young drivers. Figure 17 presents the number of saccades occurring per second related to "judgment and operation". In the figure, panel (a) shows the number of occurrences of "Time period: Daytime"; panel



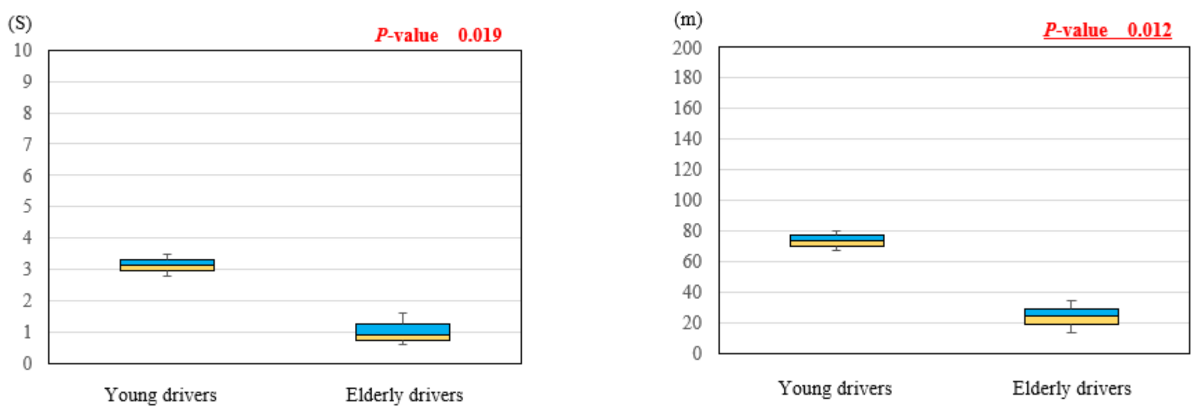
(a) Young drivers (b) Elderly drivers

Figure 14. Response time for "judgement and operations" during daytime.



(a) Young drivers (b) Elderly drivers

Figure 15. Response time for "judgement and operations" during nighttime.

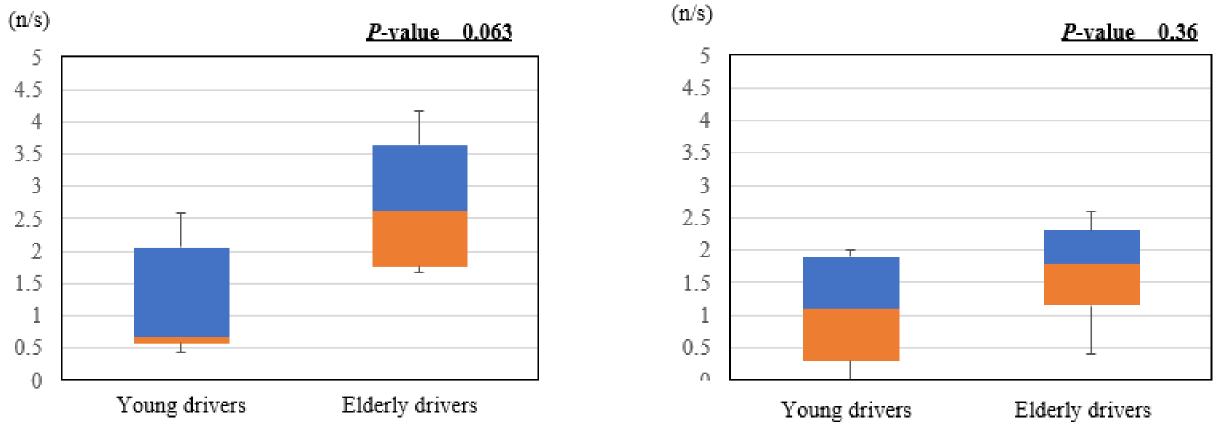


(a) Response time for "judgement and operations" (b) Moved distance for "judgement and operations"

Figure 16. Response time and moved distance for " judgement and operations " in "Time period: Nighttime" and "Overtaking vehicle: Yes".

(b) shows the number of occurrences of "Time period: Nighttime". Differences between the elderly drivers and the young drivers are apparent. However, both (a) and (b) include datasets on the presence or absence of the overtaking vehicle.

In "Time period: Daytime", the saccade frequency of the elderly drivers is higher than that of the young drivers. In contrast, their difference is not recognized in "Time period: Nighttime". The reason is the following. During the daytime



(a) Time period: Daytime (b) Time period: Nighttime

Figure 17. Number of saccade occurrences for "judgement and operations"

with good visibility, we surmise that elderly drivers performed more peripheral recognition for safety confirmation than young drivers did, based on their experience. During nighttime with poor visibility, the number of occurrences is suppressed by the effective field narrowing of each driver. The influence is inferred to have strongly affected the elderly drivers.

Taken together, the results described above confirmed that the reaction time related to "cognition" for these driving behaviors increases concomitantly with aging. In subsequent driving behaviors related to "judgment and operation", the elderly drivers tended to drive well based on their experience. However, in "Time period: Nighttime" with poor visibility, we assume that peripheral recognition for safety confirmation was disturbed by field narrowing of the elderly drivers.

V. CONCLUSION AND FUTURE WORK

For this study, we defined four situations that are likely to trigger accidents on highways as driving hazards, i.e., vehicle breakdown, sudden appearance of small animals, falling objects, and lane decrease. By running experiments conducted while controlling the time period (daytime or nighttime) and the traffic flow (overtaking vehicle: Yes or No), we undertook comparative analysis for each driving hazard, particularly addressing driving characteristics of young drivers and elderly drivers related to "cognition", "judgment", and "operation". Results clarified the following points.

- Because of "cognition", the response time of young drivers of "Overtaking vehicle: Yes" was longer than that of "Overtaking vehicle: No" in both daytime and nighttime. Particularly, in "Time period: Nighttime", significant difference ($p = 0.04$) was found.
- Regarding elderly drivers, irrespective of the presence or absence of an overtaking vehicle, the response time related to "cognition" of "Time period: Nighttime" was shorter than that of "Time period: Daytime". Particularly, for "Overtaking vehicle: No", significant difference ($p = 0.034$) was found.
- For "Time period: Daytime" and "Overtaking vehicle: No", the response time and the moved distance related to "cognition" of the elderly drivers are longer than that of the young drivers. Particularly, significant difference of the moved distance ($p = 0.09$) was found.
- Regarding young drivers, the response time because of "judgment and operations" of "Overtaking vehicle: Yes" was longer than that of "Overtaking vehicle: No" in nighttime. Significant difference ($p = 0.007$) was found.
- Regarding elderly drivers, the response time because of "judgment and operations" of "Overtaking vehicle: Yes" was longer than that of "Overtaking vehicle: No" in daytime. Significant difference ($p = 0.024$) was found.
- For "Time period: Nighttime" and "Overtaking vehicle: Yes", the response time and the moved distance related to "cognition" of the elderly drivers was shorter than that of the young drivers. Particularly, significant difference of the moved distance ($p = 0.012$) was found.

Future work will be undertaken to construct a dangerous-driving prediction model based on findings obtained from this study with the aim of improving the prediction model accuracy.

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