Analysis of Cognitive Functions in the Encountered State of Driving Topics on Expressways

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Abstract **- For this study, we defined four situations that are likely to trigger accidents on highways as driving topics, i.e., breakdown vehicles, sudden appearance of small animals, falling objects, and lane decreases. Carrying out running experiments controlling the time period (daytime or nighttime) and the traffic flow (overtaking vehicle: Yes or No), we studied the comparative analysis for each driving topic, focusing on driving characteristics of young drivers and elderly drivers concerning to "cognitions", "judgments", and "operations". Using evaluation experiments, we try to analyze the driving characteristics of elderly drivers for driving topics encountered on highways based on comparing to young drivers.**

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

I. INTRODUCTION

Although the number of deaths due to traffic accidents in Japan is on a downward trend, traffic accidents caused by erroneous operations by elderly drivers and reverse runs of highways have become particularly problematic in recent years. Regarding deaths by age group due to traffic accidents in June, 2015, elderly people over 65 years old (1,006 people, the composition ratio was 53.1%) were the most frequent, followed by the 50s (200 people, the composition ratio was 10.6%), the 40s (169 people, the composition ratio was 8.9%) in this order [1]. Looking at the trend over the past 10 years, although the overall trend is in a decreasing trend (0.60 times in 2005), the rate of decrease in elderly people is low, it is reported that elderly people are the most frequent for eight consecutive years [1], even in the number of fatal accidents by age group such as automobile drivers. As described above, traffic accidents caused by elderly drivers are relatively frequent and have a high risk of leading to serious injury, so it is urgent to take countermeasures towards the arrival of a super aging society coming close to us.

As a factor of traffic accidents by elderly drivers, there may be common points unique to the elderly, such as slowing down a series of driving operations related to cognitions, judgments and operations, miss operations of handles and brakes due to distribution of attention to multiple tasks and concentration, momentary driving due to carelessness and distraction. Recently, various traffic accident preventive safety systems have been studied, as symbolized by automatic driving efforts, and practical application of these systems has been accelerating. However, most of those systems collect and analyze external information of the vehicle, and there is a problem, which cannot adaptively deal with the driving characteristics of individual drivers. Also, with preventive safety technology based on a standard general driver, it is difficult to deal with the slowing down of the driving behavior peculiar to the elderly found in recognition, judgment and operation. Therefore, approaches to preventive safety systems dedicated to driving characteristics of elderly drivers are indispensable.

In this research, we define the four driving situations that are likely to trigger accidents as driving topics, such as breakdown vehicles with road shoulder, sudden appearance of small animals, falling objects, and lane decrease, especially for highways with high mortality rate and easy to lead to serious accidents. Then, we carry out running experiments controlling the time period (daytime or nighttime) and the traffic flow (overtaking vehicle: Yes or No). Specifically, paying attention to a series of driving behaviors related to cognitions, judgments and operations for each driving topic, and we will compare and analyze the driving characteristics of young drivers and elderly drivers. Acquiring the head posture, face orientation, eye-gaze, which are less burdens on the driver as body information indicating the driving characteristics by unconstrained means, heartbeat as biological information, handle, brake, and accelerator as each operation, we will clarify the driving

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characteristics of elderly drivers for driving topics encountered on highways.

This paper is presented as follows. We review related work to clarify the position of this study in Section II. Section III presents a definition of the experimental protocols, driving topics, and running scenarios. In Section IV, we examine the correspondence relationship between measurement points of driver reaction and eye-gaze information, focusing on the reaction time required for each action, i.e., cognitions, judgments, and operations for the driving topics. Additionally, we compare the average of reaction times of whole 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

The cause of fatal accidents of elderly drivers is mostly unsuitable for driving operation and is attributed to physical characteristics, psychological characteristics, driving characteristics, and social characteristics. Physical characteristics indicate declining physical function such as vision and exercise ability. As such assistive technologies, systems reducing the operation load of steering, systems automatically reducing the speed and damage when there is a possibility of collision, they have been putting into practical use [2]. The psychological characteristics mean that elderly drivers are not good at parallel processing of multiple information and have a tendency to become self-oriented. The driving characteristics refer to mismatch of consciousness and behaviors caused by "accustomed" or "driving that would be" based on past experiences. Additionally, the social characteristics refer to differences in characteristics by generations, such as a decline in communication skills and the influence of motorization [3]. As solutions to these characteristics of elderly drivers, the followings have been reported. It is possible to reform consciousness and motivate for safe driving by having each elderly participate in efforts for traffic safety with their own will rather than passive [3]. The elderly drivers are able to improve attention by pointing and designating the signs to recognize.

Furthermore, as a study on the cognitive function of elderly drivers, Takahara et al. [5] analyzed the characteristics at the temporary stop location, and demonstrated the effectiveness of their system through the development of a voice guidance type temporary stop support system. In addition, Iida et al. [6] constructed the hypothesis of the reverse running process as an example of the elderly driver's accidents on the expressway, they confirmed the psychological state and the road composition of the elderly driver when reverse running is easy to occur. However, these researches have not been analyzed focusing on the situations (driving topics) which are easy to induce accidents on highways, such as breakdown car on road shoulder, running-out of small animals, falling objects, and reduced lane during work. In this study, through driving experiments controlled the time zone and traffic flow, we analyze the series of driving behaviors related to cognitions, judgments and operations of these driving topics, and clarify the driving characteristics of elderly drivers.

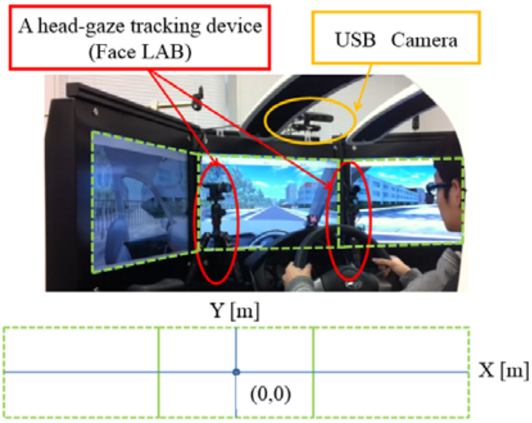


Figure 1. Experimental system for measuring driver behaviors.

III. METHODS

In this section, we define the experimental protocols and four driving topics easy to occur accidents. Next, we present running scenarios controlling daytime or nighttime, the presence or absence of an overtaking vehicle.

A. *Experimental Systems*

Though many people do driving behaviors every day, there are many difficulties to clarify individual driving characteristics from actual behaviors on the road in real environments. For example, driving behaviors vary depending on the road environment and traffic conditions at that time, and their conditions on the actual road cannot be reproduced constantly. Therefore, even if the behavior varies, it is not possible to clearly distinguish whether it is a variation due to a difference in traffic conditions or a variation among individuals.

This study used a Driving Simulator (DS) to assess driving behaviors for freely set road environments and traffic conditions that affect driver behaviors. Figure 1 portrays the experimental system configuration used 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 in the front of the cabin, and has a function reproducing pseudo-driving environments that are freely configurable to horizontal viewing angles. As Figure 1 shows, to measure body information, such as head poses, face orientations, and eye-gaze movements without restraining drivers, we installed cameras to the left and right in the center of the three-color liquid crystal monitors mounted in front of the cabin. Additionally, we set an infrared pod on top of the instruments in front of the cabin. Here the camera heads and infrared pod are input-based sensors of a head-gaze tracking device (FaceLAB; Ekstreme Machine Corp.). Incidentally, through preliminary test runs by multiple subjects, we confirmed that installation of the stereo camera head and infrared pod does not interfere with visibility during driving operations. Furthermore, in order to capture the facial expressions of drivers, an USB camera (Xtion pro Live) was installed at the top of the liquid crystal monitor on the center in front of the cabin.

B. *Experimental Protocols*

Figure 2 depicts the experimental protocol outline. Initially, as individual characteristics of each subject, we conducted an examination of the following questionnaire methods: attitude, oriented, and concept to work on driving were performed using the driving style check sheet [20]. Regarding the types of operation burdens that were strongly felt, they were performed using a driving load sensitivity check sheet [21]. In one running test, for each target subject wearing a heart rate monitor (RS800CX; Polar), we measured the instantaneous heart rate of a normal state during 1 min in advance. Next, to improve the measurement accuracy for face orientations and eye-gaze movements of each participant, we calibrated the cameras of the head-gaze tracking device (FaceLAB). We recorded a face video while driving with the USB camera (Xtion Pro Live; ASUS Corp.) to analyze the facial expressions of the subject. After these preparations, each participant ran along the four running scenarios described later in Section III.C, by synchronizing the time base of each measuring device. Finally, using a questionnaire that specifically examines driving topics occurring at random, subjective reviews, a four-stage check, were also conducted when a driving topic occurred. After obtaining the approval of Akita Prefectural University Research Ethics Board, the experiment contents for all subjects were explained fully to participants in advance. We obtained written consent of participants. From each, we also obtained an agreement to publish a face image along with the consent to experimental participation. Subjects were 10 young drivers (A, B, C, D, E, F, G, H, I, Q: average age 22 years) and nine elderly drivers (J, K, L, M, N, O, P, R, S: average age 62 years) in total 19 people.

C. *Driving topics and Running scenarios*

The driving course used in the experiment is a straight course with no lane changes of two lanes on one side

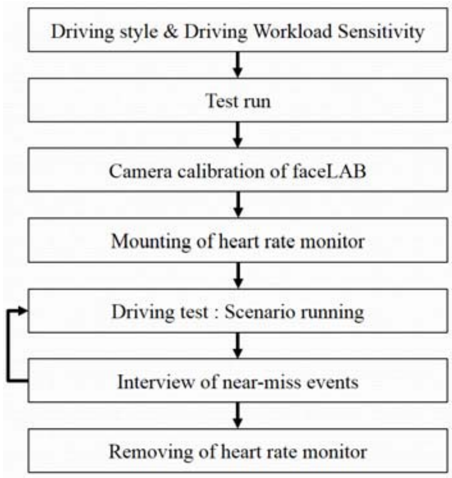
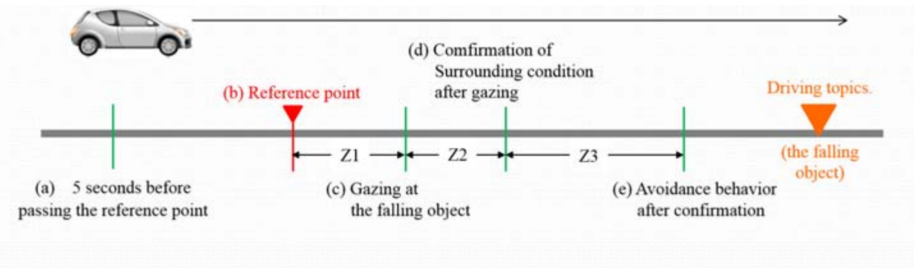


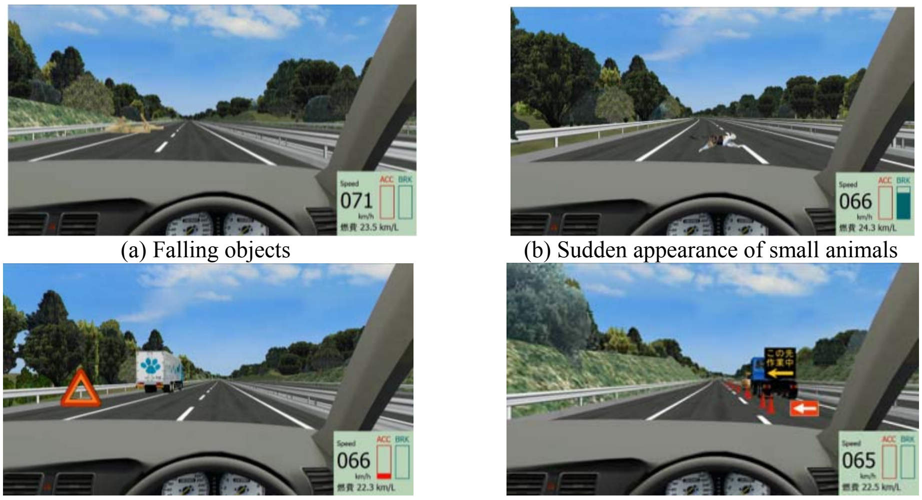
Figure 2. Outline of experimental protocols.



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

Z1 3.28sec Z2 0.33sec Z3 2.37sec

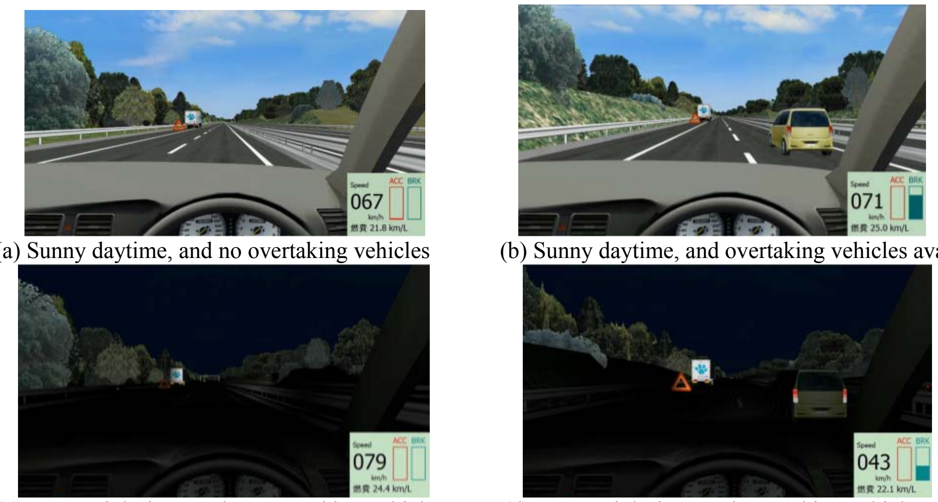
Figure 3. Measurement points of driver reaction to driving topics.



(a) Falling objects (b) Sudden appearance of small animals

(c) Breakdown vehicles (d) Lane decrease during work

Figure 4. Driving topics for running test.



(a) Sunny daytime, and no overtaking vehicles (b) Sunny daytime, and overtaking vehicles available

(c) Sunny nighttime, and no overtaking vehicles (d) Sunny nighttime, and overtaking vehicles available

Figure 5. Running scenarios.

simulating the Tohoku Expressway, and starts running from the driving scene that converges from the acceleration lane to the expressway. Driving topics occurred in one running were set randomly, and the measurement points of the driver's reaction for each driving topic were set as shown in Figure 3. Figure 4 presents the state of each driving topic. The falling object in Figure 4 (a) is installed in the center of the left lane, and 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 so as to close the driving path of the concerned vehicle. The breakdown vehicle in Figure 4 (c) simulated a state where a large truck was parked on the shoulder due to a failure. With the lane decrease in Figure 4 (d), the overtaking lane is unavailable due to in-work and decreases from 2 lanes to 1 lane. In the case where each driving topic and the concerned vehicle come into contact, characters of "collision" are displayed on the front screen, but running experiments can be continued.

Subsequently, we present an overview of running scenarios in the following sentences. To take into account the differences in visibility due to time periods, 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 topic. Figure 5

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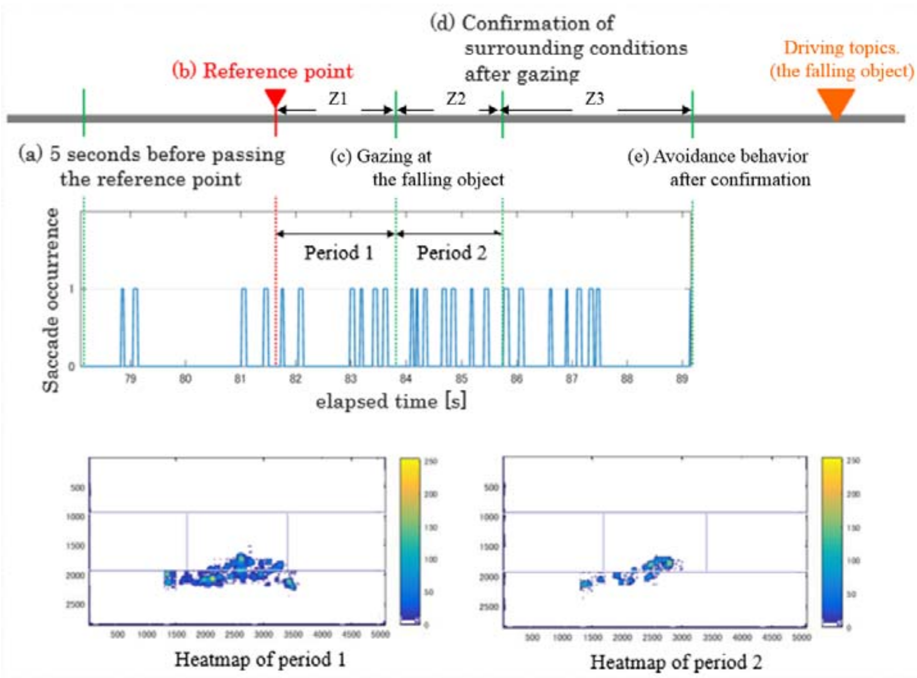


Figure 6. Time series changes of heatmaps and saccades corresponding to each measurement point.

presents four types of driving scenarios that controlled time periods (i.e., daytime or nighttime) and traffic flows (i.e., overtaking vehicles: Yes or No). The order of occurrence of each driving topic was two patterns of 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 to 10 minutes, and we gave instructions to each subject to observe the speed limit of 100 (km / h). Additionally, maximum speed was automatically limited to 120 (km / h) on DS side.

IV. EXPERIMENTAL RESULTS AND ARGUMENTS

Based on safety confirmation behaviors due to the driving topics, we analyzed reaction times of whole drivers, elderly drivers, and young drivers at each measurement point. Finally, we discussed the differences of driving characteristics between elderly drivers and young drivers, focusing on "cognitions", "judgments", and "operations".

A. Measurement points and driver response for driving topics

Focusing attention on eye-gaze behaviors for driving topics and safety confirmation behaviors due to lane change, we will examine the correspondence relationship between measurement points of driver reaction and eye-gaze information (i.e., heat maps, saccades) as shown 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) avoidance actions. In addition, the time series changes of saccades are divided into two sections, i.e., from a) 5 seconds before passing the reference point to b) passing the reference point, from b) passing from the reference point to e) avoidance action. Focusing on the time series changes of heat maps and saccades in Figure 6, we are able to confirm driver states related to the attention to the falling object and the surrounding situation confirmation due to lane change. Consequently, based on the vehicle speed of b) the reference point during the passage, it is possible to estimate the reaction time required for each action, i.e., cognitions, judgments, and operations for the falling object.

B. Analysis of Driver Response to Falling Objects

Figure 7 shows the average of reaction times of whole drivers, elderly drivers, and young drivers at each measurement point for "falling objects" which is one of the driving topics. In Figure 7, the respective reaction times are as follows.

1) from b) passing the reference point to c) falling object gazing,

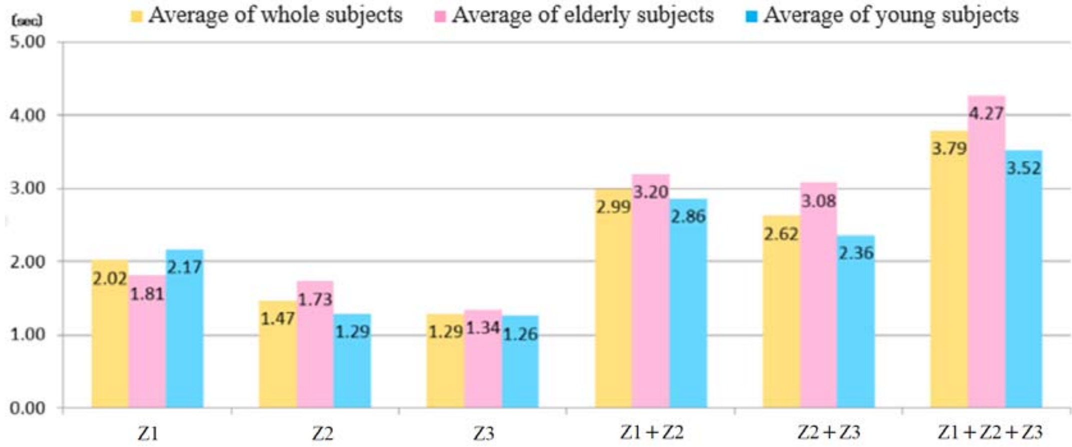


Figure 7. Driver's reaction time to falling objects.

2) from c) falling object gazing to d) surrounding situation confirmation,
3) from d) surrounding situation confirmation to e) avoidance behavior

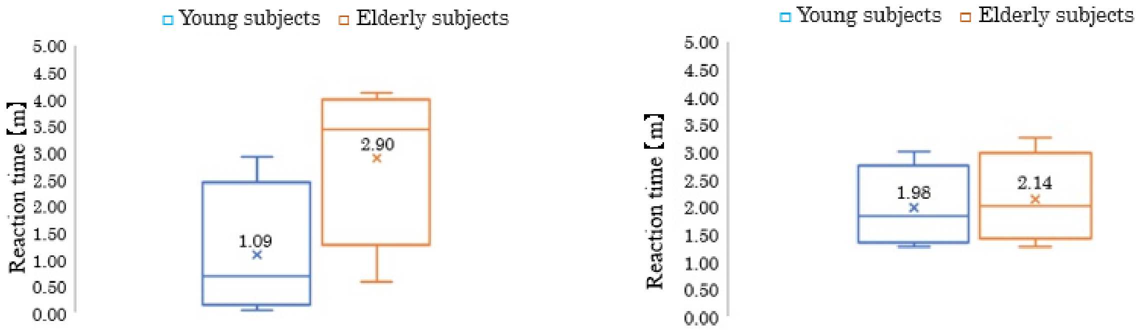
When analyzing a series of driving behaviors related to cognitions, judgments and operations for falling objects, the elderly drivers generally tended to have longer reaction times than those of young drivers. Furthermore, by classifying each driver based on the average of the whole subjects and paying attention to the relationship 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 is late, operation is gradual (i.e., cognition, judgment, and operation are gentle)
· Group D: all reactions are average (i.e., cognition, judgment, and operation are all average)

The young drivers are classified into Group A and Group D, whereas the elderly drivers are more likely to be classified as Group B and Group C. In addition, we believe that the characteristics of driving behaviors will shift from group B to group C as the aging of driver progresses.

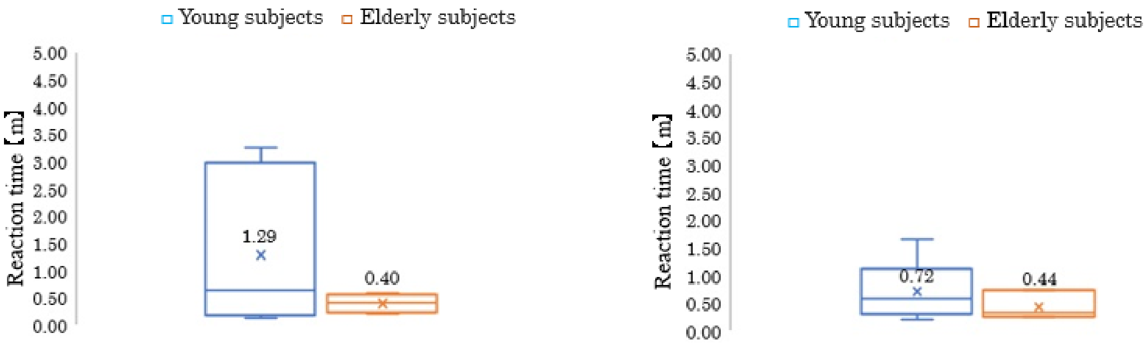
C. Comparison of elderly drivers and young drivers

In Section IV.B, as the result of analyzing a series of reaction times related to cognitions, judgments and operations for falling objects, we confirmed that each driver has a strong tendency to be classified as one of four groups (i.e., A, B, C, and D). In order to further clarify the driving characteristics of elderly drivers, we try to analyze each reaction time of elderly drivers and young drivers, for running scenarios that controlled the time periods (i.e., daytime or nighttime). However, we set the condition that no overtaking vehicle occurs in any case. We show reaction time (Z1) for "cognitions" in Figure 8, reaction time (Z2) for "judgments" in Figure 9, and reaction time (Z3) for "operations" in Figure 10 separately. In these figures, (a) shows the result of daytime, and (b) shows the result of nighttime. Focusing on the reaction time (Z1) pertaining to "recognition" in Figure 8, when the time period is daytime, the reaction time of the elderly drivers is significantly longer than that of the young drivers. On the other hand, when the time period is nighttime, the difference between the elderly drivers and the young drivers is hardly noticed. Generally, the visibility at nighttime is considered to be deteriorated. However, according to the questionnaire survey after the running test, the majority accounted for the elderly drivers as "the nighttime course was easier to recognize the falling objects". The reason for this trend may be attributed to the factor that eye-gaze targets during nighttime driving were limited. In the reaction time (Z2) related to "judgment" in Figure. 9, we can confirm that the reaction time of elderly drivers is significantly shorter than that of young drivers in both time periods (i.e., daytime and nighttime). This is because the elderly drivers are rich in driving experience compared to the young drivers, so we can infer that this trend is due to differences in their experiences. In the reaction time (Z3) related to "operation" in Figure 10, almost no difference is observed when the time period is daytime. On the other hand, it can be confirmed that there is a large variation in reaction time of the elderly drivers in nighttime. Comprehensively, analyzing the above results,



(a) Daytime / no overtaking vehicles (b) Nighttime / overtaking vehicles available

Figure 8. Cognitive reaction time (Z1).



(a) Daytime / no overtaking vehicles (b) Nighttime / overtaking vehicles available

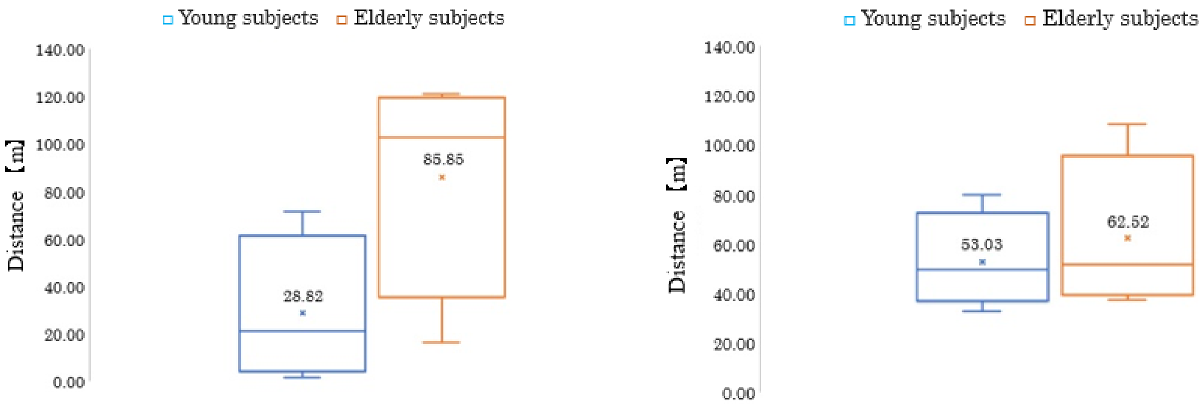
Figure 9. Reaction time for judgments (Z2)

(a) Daytime / no overtaking vehicles (b) Nighttime / overtaking vehicles available

Figure 10. Reaction time for operations (Z3)

we confirmed that the reaction time (Z1) related to "cognition" of the elderly drivers is longer and the reaction time (Z2) related to "judgment" is shorter than those of the young drivers.

Finally, the distance from the reference point to the falling object was calculated based on the reaction time (Z1) related to "cognition" and the speed at the time of passing through the reference point. The results are shown in Figure 11. In this section, we calculated the moving distance for all subjects assuming constant linear motion. The clear difference can be confirmed as compared with the reaction time in Figure 8. As we can understand from Figure 11, among a series of driving behaviors, the driving characteristics related to "cognition" are greatly different between the young drivers and the elderly drivers. Consequently, we infer that the difference will greatly affect "judgment" and "operation" thereafter. Particularly, the elderly drivers have a high ability to judge based on their



(a) Daytime / no overtaking vehicles (b) Nighttime / overtaking vehicles available

Figure 11. Distance from the reference point to the falling object.

experiences. The following framework is effective for elderly drivers, i.e., which will refine the gazing target necessary for safety driving appropriately, and direct caution resources to the gazing target at the same time.

V. CONCLUSION AND FUTURE WORK

For this study, we defined four situations that are likely to trigger accidents on highways as driving topics, i.e., breakdown vehicles, sudden appearance of small animals, falling objects, and lane decrease. Carrying out running experiments controlling the time period (daytime or nighttime) and the traffic flow (overtaking vehicle: Yes or No), we studied the comparative analysis for each driving topic, focusing on driving characteristics of young drivers and elderly drivers concerning to “cognitions”, “judgments”, and “operations”. Results clarified the following points.

- The elderly drivers had longer reaction times than young drivers. Particularly, the reaction time regarding to “cognitions” was remarkable.
- Based on the average of whole subjects, the existence of categories characterizing elderly drivers was confirmed from the relationship between the reaction time of each driver and driving style.
- For elderly drivers, it is effective to narrow down gazing targets necessary for safety driving and allocate appropriate attention resources.

In future work, we aim to evaluate the statistical superiority of the findings obtained in this research and aim to improve the accuracy of a dangerous driving prediction model.

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