SPEED ANTICIPATION CHARACTERISTIC WITH OPTICAL FLOW FOR DRIVER BEHAVIOR ASSESSMENT OF OLDER DRIVERS

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Summary: The objective of this study is to clarify the relationship between the speed anticipation characteristic with optical flow derived from self-motion and driver behavior of older drivers for future driver assessment. We focused on speed anticipation with optical flow because anticipated speed is assumed to influence behavior at unsignalized intersections with limited visibility, which is an accident-prone situation for the older drivers in Japan. To assess the characteristic, we constructed a novel test by revising a similar test. We conducted an experiment with older drivers that consisted of the novel test and an on-road driving test. The experiment results showed that the speed anticipation characteristic with optical flow had a significant effect on older drivers' behavior at intersections and drivers who anticipated speed faster drove slower and safer.

INTRODUCTION

In Japan, the total number of traffic accidents is decreasing. However, traffic accidents caused by older drivers (aged 65 and over) are not. Among older drivers, crossing accidents at unsignalized intersections are the most common accident scenario (Shibasaki et al., 2017). Studies on driver assistance and education systems are important to decrease these traffic accidents. Driver characteristics, such as cognitive ability and driving style, differ between individuals. Therefore, it is necessary to support drivers by identifying the relationship between driver characteristics and unsafe driver behavior. Relationships between the characteristics of older drivers and their crash involvement and driving errors have been investigated in many studies. However, little research has focused on the relationship between driver characteristics and driver behavior in specific scenarios, such as passing through unsignalized intersection behaviors.

Hashimoto et al. (2010) reported that older drivers reduce speed less and make fewer checking actions when passing through unsignalized intersections compared to other age groups. Especially at intersections where visibility is limited, speed adjustment and checking behavior would be influenced by a driver's anticipation of the speed of objects rushing out from the intersection's blind spot that are not visible. The speed of the objects is typically anticipated while approaching the intersection at low speed, that is, while moving with low-speed optical flow derived from self-motion. However, previous studies note that older adults have difficulty in processing speed information while moving (Anderson et al., 2000; Anderson & Enriquez, 2006) and this may lead to inaccurate speed anticipation of the objects and driver behavior.

Drivers who anticipate the speed of objects slower due to the influence of optical flow may have an unsafe driving tendency, such as setting their speed higher. Thus, the speed anticipation characteristic with optical flow is a factor that can possibly assess driver behavior. Therefore, we aim to clarify the relationship between the speed anticipation characteristic with optical flow and driver behavior when passing through unsignalized intersections to achieve our goal of assessing the driver behavior of older drivers. In addition, we aim to investigate the relationships between the characteristic and the cognitive ability and driving style of older drivers.

In this paper, we first describe a novel test to measure the characteristic of speed anticipation with optical flow, and we then describe the experiment, which consisted of the novel test, an on-road driving test, cognitive ability tests, and a driving style questionnaire. Lastly, we describe the relationship between the characteristic and driver behavior while passing through unsignalized intersections with cognitive ability and driving style, as based on the results. The work described in this paper was done with the approval of the ethics committee of The University of Tokyo.

METHODOLOGY

Speed Anticipation Reaction Test with Optical Flow

When crossing objects are invisible due to the limited visibility of an intersection, the moving speed of the objects cannot be anticipated by visual cues but will be anticipated based on the driver's speed anticipation characteristic that we assumed to be influenced by optical flow. To measure this speed anticipation characteristic, we revised an existing method to measure the characteristic of speed anticipation based on visual cues with optical flow and then adopted the difference between the test results with and without optical flow as an assessment index.

We revised the Speed Anticipation Reaction Test (SART) proposed by Maruyama (1980) to measure the characteristic. The original SART measures the characteristic of speed anticipation by presenting a moving target going from right to left and masking the target in a certain area as shown in Figure 1. Subjects are ordered to press a button at the time they anticipate that the target reached the anticipation point. The test measures the time gap between the actual and anticipated reaching time of the point.

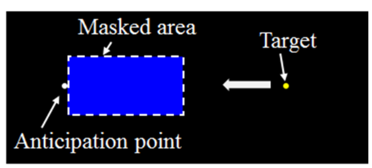
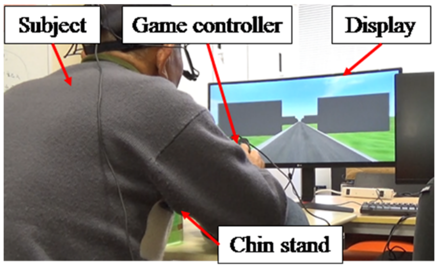


Figure 1. Speed Anticipation Reaction Test (SART)

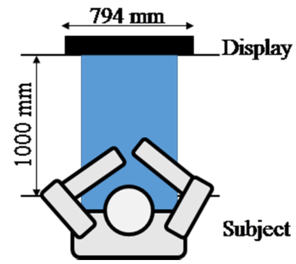
To measure the speed anticipation characteristic with optical flow, we changed the original SART task into a driving-like task by changing the moving target to a crossing vehicle and the masked area to a wall nearby an intersection as shown in Figure 2. The crossing vehicle appears and approaches the intersection at a constant speed (30 km/h). Subjects are ordered to press a button when they anticipate that the front-end of the crossing vehicle reaches the left edge of the wall. The size of the wall was set in accordance with the masked time of the original task (2,160 ms). We conducted the above test of the subject's intersection-approaching speed under two different conditions: stopping (C1) and moving at low speed (10 km/h) (C2).

Figure 2. SART with optical flow

Figure 3 shows the test situation of SART with optical flow. We created the test with UC-win/Road Driving Sim (Forum8 Co., Ltd.) and displayed it on a wide display (LG Electronics Inc.). The subjects reacted to the task with a game controller (Sony Corp.). We used a chin stand to control the distance between the subject's head and display.



(a) Side view



(b) Overhead view

Figure 3. Test situation of SART with optical flow

Subjects performed the task two times for practice and five times for measurement. We conducted the two test conditions in a fixed order, C1 first and C2 second. We adopted the speed anticipation characteristic index (*SAC*) for assessment defined as equation (1) where *MT* is the masked time of the target, RT_{C1} is the mean button reaction time of the C1 task, and RT_{C2} is the mean button reaction time of the C2 task. *SAC* represents the influence of optical flow on the speed anticipation of invisible crossing objects. Positive *SAC* indicates that the subject anticipated the speed of crossing objects faster with low-speed optical flow.

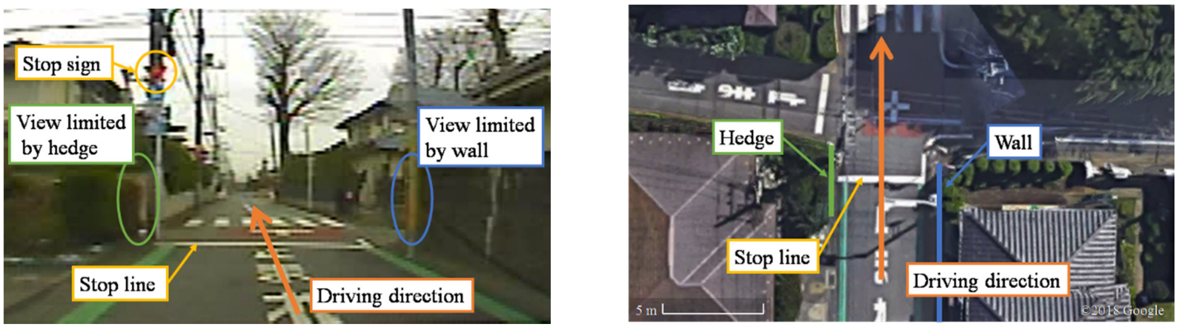
$$SAC = (MT - RT_{C2}) - (MT - RT_{C1}) = RT_{C1} - RT_{C2} \quad (1)$$

On-Road Driving Test

We conducted an on-road driving test to observe driver behavior. Subjects drove a set course on public roads with several unsignalized intersections. The course was approximately 5 km long set in a residential area. The test vehicle was equipped with a data recorder (DR) unit (Fine Fit Design, Inc.), and it recorded images from cameras (e.g., front view camera, driver face camera), vehicle behavior (e.g., speed, acceleration), and driver operation (e.g., brake signal, turn signal). We instructed the subjects to drive as usual. Driving instructors navigated the subjects through the course. In case of unsafe situations, the instructor intervened to ensure safety.

In this paper, we selected the intersection with a stop sign as the analysis target. Figure 4 shows the appearance of the intersection. Subjects drove straight through this intersection. Walls on the right and hedges on the left limited the visibility of the intersection. There was traffic from vehicles, bicycles, and pedestrians on the crosswalk in the intersection.

We selected driving behavior indices of speed adjustment and checking behavior as shown in Table 1. The definitions of each index are shown in Figure 5. Regarding the degree of speed adjustment and checking activity, we divided intersection-passing behavior into two sections by the position of the vehicle front-end. Section 1 is from the stop line to the intersection entrance and section 2 is from the intersection entrance to the exit. For the analysis of checking behavior, we classified the driver's face direction with respect to traveling direction into three categories (left, center, and right) by analyzing the face camera image manually. We determined that drivers were checking the blind spots if the face direction was classified either left or right.



(a) Driver's viewpoint **(b) Bird's-eye viewpoint**

Figure 4. Appearance of analysis target intersection

Table 1. List of driver behavior indices

Index	Definition
Speed adjustment behavior	
$AVGS_i$	Average speed of Section *i*
$MINS_i$	Minimum speed of Section *i*
ES	Speed when entering intersection
BET	Brake end timing (Positive before intersection entry)
BEL	Brake end location (Positive before intersection entry)
Checking behavior	
TCT_i	Total checking time of Section *i* ($RCT_i + LCT_i$)
CST	Checking start timing (Positive before intersection entry)
CSL	Checking start location (Positive before intersection entry)

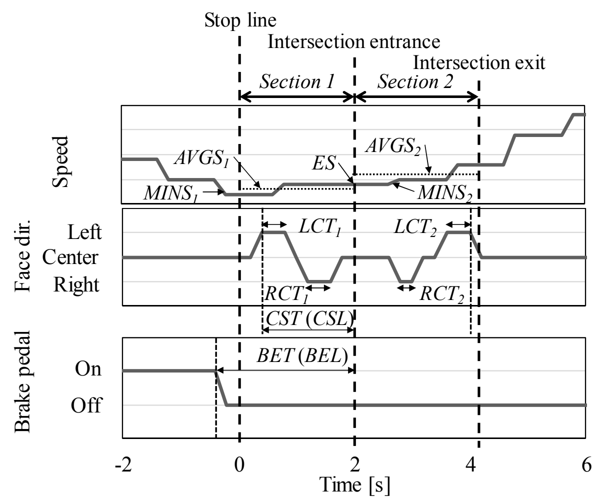


Figure 5. Definition of driver behavior indices

Cognitive Ability Tests and Driving Style Questionnaire

We conducted the following tests that have been shown to be related to the driver behavior of older drivers in previous studies: Mini-Mental State Examination (MMSE; Davis et al, 2012), Trail Making Test (TMT; Stutts et al., 1998), and Visual Field with Inhibitory Tasks (VFIT; Fujita et al., 2012). VFIT is a modified test of the conventional Useful Field of View Test (Ball & Owsley, 1993) that can assess selective attention using a PC and game controller. VFIT consists of three pre-tests and a dual task of combined pre-tests. In the dual task, a peripheral marker appears around the two target markers in the center. Subjects must push the button only when the two center markers are different. After that, subjects must push a predetermined button corresponding to the peripheral marker type. There are four levels (I, II, III, and IV) of the dual task depending on the distance between the center and peripheral marker. In this research, we adopted the peripheral error rate of the dual task in levels II, III, and IV as a test measure.

We adopted the Driving Style Questionnaire (DSQ) in Japanese (Ishibashi et al., 2007) to grasp the driving style. This questionnaire consists of 18 questions and interprets the respondents' driving style with eight scales (e.g., Confidence in driving skill, Anxiety about traffic accidents).

Participants and Procedure of Experiment

Thirty-three older drivers (*M* age 76.1 years, *SD* = 3.6) participated in the experiment consisting of the SART with optical flow, on-road driving test, cognitive ability tests, and DSQ. Every participant had generally good health, drove more than once a week, and possessed a valid driver's license at the time. The experiment was done on two different days. The on-road driving test and cognitive ability tests on the first day, and the SART with optical flow on the second day. The participants were provided with a thorough explanation of the nature of the experiment and informed consent was obtained from each participant before the experiment.

Data Analysis

We divided the participants into two groups based on the results of the SART with optical flow to investigate the relationships with the speed anticipation characteristic with low-speed optical flow. One group was the higher speed anticipation (HSA) group which anticipated the speed of the crossing vehicle faster with optical flow ($SAC \geq 0$), and the other was the lower speed anticipation (LSA) group which anticipated the crossing vehicle's speed slower ($SAC < 0$). The results of the tests and questionnaire were compared between the two groups.

RESULTS

Driving data from one participant was not recorded due to a malfunction with the DR unit. Four participants were subjected to interventions from the instructor at the analysis-target intersection for safety reasons. Therefore, five participants were excluded and the data of the remaining twenty-eight participants were analyzed.

There were significant differences between the two groups in checking start location (*CSL)* (Figure. 6 (a)) and checking start timing *CST* (Figure. 6 (b)). The HSA group tended to start checking earlier than the LSA group. In addition, total checking time (TCT_1) was longer (Figure. 6 (c)), average vehicle speed ($AVGS_1$) was lower (Figure. 6 (d)), and the intersection-approaching speed was lower (Figure. 6 (e)) for the HSA group.

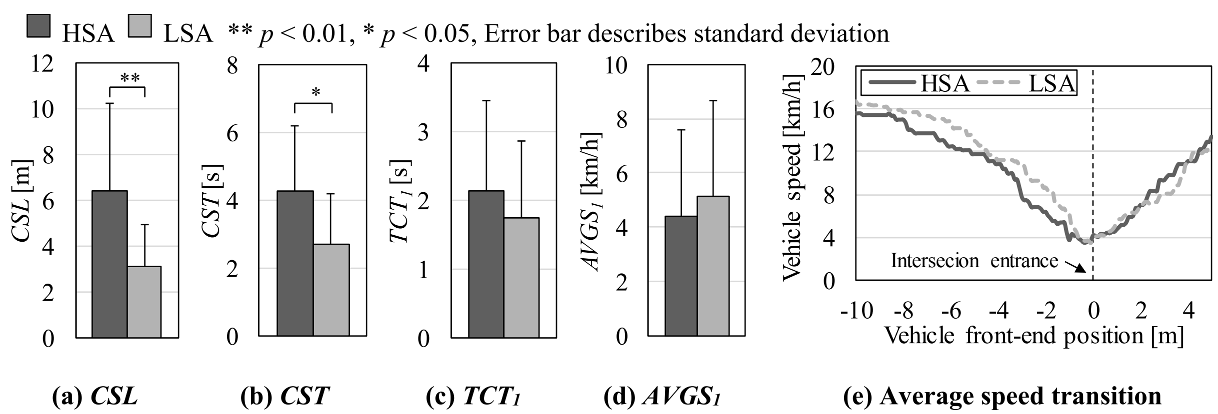
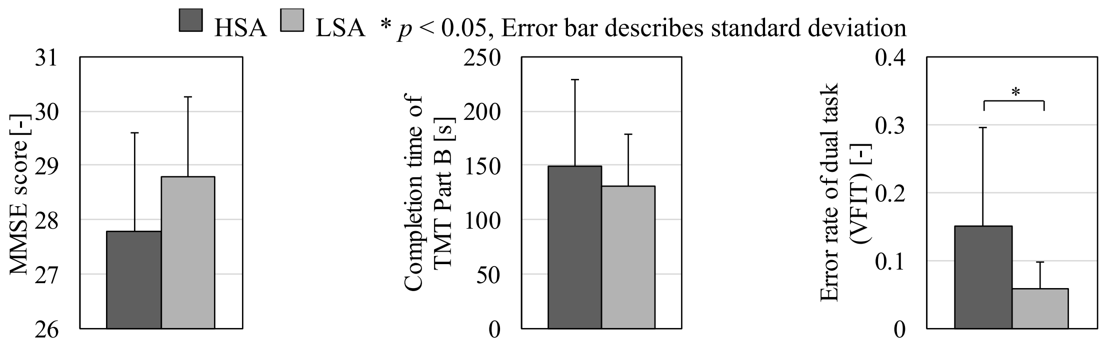


Figure 6. Comparison of driver behavior between HSA and LSA

Participants classified as HSA had lower MMSE scores (Figure. 7 (a)) and took a longer time to complete TMT Part B (Figure. 7 (b)) compared to the LSA group. Moreover, the HSA group significantly made more peripheral errors during the dual task of VFIT (Figure. 7 (c)). The results of DSQ showed that drivers of the HSA group tended to be more anxious about traffic accidents compared to the other group. Participants belonging to the HSA group had lower cognitive ability and were more concerned about accidents.



(a) MMSE score **(b) Completion time of TMT Part B** **(c) Error rate of dual task (VFIT)**

Figure 7. Comparison of cognitive ability between HSA and LSA

DISCUSSION

The analysis results indicated that drivers who anticipated the speed faster with optical flow tended to start their checking behavior at significantly farther distances from the intersection. From this, it could be said that the speed anticipation characteristic with optical flow is related to driver behavior at unsignalized intersections. Moreover, the drivers who anticipated the speed of crossing objects faster due to the influence of optical flow exhibited safer behavior. Therefore, speed anticipation characteristics with low-speed optical flow can be used to assess unsafe behavior in older drivers.

The results of cognitive ability tests indicated that the participants who anticipated the speed faster had relatively lower cognitive ability. From this fact, drivers who drove slower and safer had a lower cognitive status. In addition, they were more anxious about driving. Previous studies have shown that cognitive status (Devlin & McGillivray, 2016) and driving anxiety (Gwyther & Holland, 2012) affect self-regulation in driving. Hence, it is suggested that faster speed anticipation and safer driving behavior were consequences of compensating behavior of cognitively declined and anxious drivers.

This study has some limitations. The sample size of older drivers was relatively small and consisted mainly of a group of motivated adults. Therefore, the findings in this study cannot be generalized based on this study alone. Another limitation is the fact that driver behavior was analyzed using a single intersection. To make the results of this study more stable, analyses of behavior while passing through other intersections are necessary and this will be our future work.

CONCLUSION

To clarify the relationships between the speed anticipation characteristic with optical flow and driver behavior when passing through unsignalized intersections, we constructed a novel test to measure the characteristic and investigated its relationship with driver behavior by conducting an experiment with older drivers that consisted of a novel test, an on-road driving test, cognitive ability tests, and a driving style questionnaire. The following are our conclusions:

- The speed anticipation characteristic with optical flow has a significant effect on driver behavior at unsignalized intersections and has the possibility to assess the safeness of the behavior where faster speed anticipation of invisible objects at intersections are safer.
- Older drivers who anticipate the speed of invisible objects faster and practice safer behavior had lower cognitive ability and were more anxious about traffic accidents. The faster-speed anticipation characteristic may be a consequence of the elderly's compensating behavior.

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