Effect of Pursuit Eye Movement and Attentional Allocation on Perceptual-Motor Prediction in the Speed Anticipation Reaction Test

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In traffic psychology, the Speed Anticipation Reaction Test (SART) is an experiment that examines perceptual-motor coordination. In this experiment, a target stimulus moves at a constant speed towards the center of the screen from the right-hand side and is hidden by a black frame in the middle. Participants are required to press a mouse button at the point at which they anticipate the target stimulus will reach the goal stimulus on the left. I have investigated possible influences that would affect the accuracy of predicting speed accrual in SART, whether or not pursuit eye movement is necessary to track the target stimulus, and how the allocation of attention would affect this. The results showed that the important influences on accurate speed accrual were pursuit eye movements that track the target stimulus and the allocation of attention onto the target stimulus in instances of internal pursuit when it is not possible for participants to carry out a pursuit eye movement. This study was undertaken in order to grasp the accuracy of visual information while driving. In these situations, it is important for the driver to make pursuit eye movements to perceive important objects as well as follow the internal pursuit signal with sufficient attention for objects that are in one's peripheral vision.

Keywords: Speed Anticipation Reaction Test, perceptual-motor coordination, pursuit eye movement, internal pursuit, attention

Introduction

Perceptual-motor coordination is an exercise that has many day-to-day functions. For example, the driver of a vehicle can watch and predict activity on the road, and if a pedestrian crosses the road, the driver can consequently operate the steering wheel and accelerator appropriately so that the car does not collide with them. Both visual information processing to predict the motion of exterior objects and motor reactions based on accurate predictions become appropriately coordinated. Ball games such as soccer and the baseball are similar. We raise a leg and swing a bat based on the accurate prediction and confirmation of the position of the ball. One is required to move after perceiving exterior visual objects in an exact coordination of perception and motor skills.

In this study, I examined the effects of pursuit eye movement and pay attention to the accuracy of predicting perceptual motion. To examine these faculties, I used a method taken from the Speed Anticipation

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Reaction Test (SART) (Maruyama & Kitamura, 1966; Yuze, Tada, Yoshida, & Hatayama, 1993), which is used in traffic psychology as an aptitude test for drivers. Figure 1 demonstrates an experiment from SART. A blackball (i.e., the *target stimulus*) on the right-hand side of the screen moves towards the left inside of the horizontal white frame at a constant speed, and is hidden when it enters the horizontal black frame. Participants are required to press a mouse button at the point at which they anticipate the target stimulus will reach the black ball (i.e., the *goal stimulus*) on the left, assuming that the target stimulus will continue at a constant speed after having entered the black frame. In a driving situation, the perception of the target stimulus represents the visual information processing of walkers, cars, and traffic signals. Similarly, pressing a mouse button represents the action of employing the accelerator, the brake, and the steering wheel. According to Nakazono and Kobori (2008), information processing is needed for SART as follows: (1) Participants grasp the position and direction of the moving target stimulus and the position of the goal stimulus; (2) they grasp the speed of the target stimulus; (3) they predict the moment in time that the target stimulus will reach the goal stimulus; and (4) they press a button.

Figure 1. An experimental procedure of Speed Anticipation Reaction Test (SART) in Experiment 1.

Maruyama and Kitamura (1966) identify “an early reaction” and “a delay reaction” when participants press a key earlier or later than the moment when the target stimulus reaches the goal stimulus, respectively. It emerged in a comparison between an accident-frequent group and a rare-accident group that the accident-frequent group tended to react early in SART. The early reactions were interpreted as a dominance of the motor reaction without an accurate prediction of the movement of visual objects. Hosokawa, Hashimoto, Hiramatsu, Sunda, and Yoshida (2018) classified old-aged drivers according to nine characteristics by cognitive function (normal, slight drop, and drop) $\times$ reaction tendency (normal, early, and delayed) through analyzing the experimental data in SART. Using a drive recorder, they recorded and analyzed how the nine types of old-aged participants drive in daily life. They demonstrated the category of background and factor for nine old-aged groups to drive unsafely, and could instruct them on how to drive safely.

In this study, pursuit eye movement and attention to target stimuli would affect the accuracy of reaction and the tendency towards early or delayed reactions in SART. A preliminary study on the effect of pursuit eye movement in SART includes Nakazono and Kobori (2008). They made some experiments in SART using both the *ordinary* method and the *extinction* method that the target stimulus disappears halfway. The results showed that the *time error*, that is, the difference between the timing when the target stimulus arrives at the goal stimulus and the timing when the participants press a key, was small in an ordinary SART. Participants demonstrated the correct reaction regardless of the moving target’s speed and the various positions of the

horizontal frame. Participants had the ability to grasp and predict the speed of the target stimulus and estimate when to press the button. Conversely, the time error was more significant in the extinction method than in the ordinary method in SART, but it gradually decreased with repeated trials. This proves the effect of learning. Furthermore, pursuit eye movement appeared more frequently in the extinction method, which revealed that participants tried to grasp the motor speed of the target stimulus more carefully.

A preliminary study on the effect of attention on SART includes Furuki, Abe, Yamanaka, Morishima, and Daimoto (2012). They examined the eye movements of a driver occupied in various mental tasks, namely numerical tasks with three conditions (none, *repetition*, and *addition*). In the repetition task, participants were required to read one column of numerical values aloud after hearing it, and in the addition task they heard two repeated numbers and had to read only one column of the two added numbers. The results showed that the load of numerical tasks were increased in the order of none, repetition, and addition. When the load was increased, eye movements occurred less frequently and, consequently eye fixation time increased. The increase of fixation time was interpreted as a delay in the acquisition and processing of visual information. Takano, Imazeki, Nishiguchi, and Karashima (2015) examined the influence of conversation on visual information recognition in a task that required participants to press a key the moment when a target color appeared as a signal. In experiments, there were two kinds of dual tasks. One was numerical addition using short-term memory, and the other, called *Shiritori*, was a conversation using long-term memory. *Shiritori* is a word game in Japan in which one player has to say a word starting with the last syllable of the word given by the previous player. The results showed that the reaction time on the key press was fastest in order of none, numerical addition, and *Shiritori*. The results demonstrated that conversation in long-term memory decreased the participant's attention span and reduced the ability to grasp the visual information needed, and caused a delay in response.

The present study had three experiments in driving situations. They were as follows:

- Pursuit eye movement in Experiment 1: One can drive with pursuit eye movements on various visual objects in central vision.
- Internal pursuit in Experiment 2: One can drive with internal pursuit in peripheral vision with no pursuit eye movement in central vision. For example, one has to grasp a situation such as pedestrians on the road in peripheral vision while focusing on an object in central vision.
- Internal pursuit with little attention in Experiment 3: One can have little attention to the various objects in peripheral vision while driving. For example, one can have little attention on perceiving a situation such as pedestrians on the road in peripheral vision while allocating much of one's attention to watching the car navigation system carefully.

I examined the effects of pursuit eye movement and attention in SART by making two comparisons of Experiment 1 and 2, and Experiment 2 and 3, respectively.

Method

Participants

Ten participants (21-34 years old) who had satisfactory visual acuity with 1.0 or more participated all of three experiments.

Apparatus

The stimuli were presented on a 17-inch monitor at a visual angle of $19.4^{\circ} \times 24.2^{\circ}$, with a refresh rate of 85Hz (SOTEC CP17K1), controlled by a personal computer (SOTEC M380AV).

Stimuli

The background luminance on the display was 90.7 cd/m^2 , and the luminance of the target stimulus, the black ball, was 0.84 cd/m^2 . The distance between the display and the participants was 80 cm. As shown in Figure 1, a figure composed of a white and black frame and two black balls positioned right and left was presented on the display. After participants pressed a mouse button, the right black ball (*target stimulus*) moved towards the left black ball (*goal stimulus*) at a constant speed of 1.89 deg/second . The visual angle of the diameter of the target stimulus and width of the linked horizontal frame with black and white was 0.57° and 7.12° , respectively. To avoid participants being able to memorize the timing of when to press the mouse button through repeating trials, the position of the goal stimulus and the width of the horizontal black frame were slightly altered between trials.

As shown in Figure 2, a fixation point “+” was presented in Experiment 2, and one Chinese character with 13 to 14 line drawings was presented in Experiment 3. The visual angle from the fixation point and the Chinese character to the goal stimulus was 3.42° .

Figure 2. An experimental procedure of SART. (a) Participants are required to keep gazing at focus point “+” in Experiment 2. (b) Participants are required to count the number of lines in the Chinese character in Experiment 3.

Procedure

In each experiment, nine out of ten participants had 20 trials, and only one had 30 trials. Each trial was conducted in Experiments 1 to 3 as follows:

Experiment 1. The target stimulus on the right moved into the goal stimulus on the left at a constant speed, as shown in Figure 1. Participants pressed a mouse button when they judged that the target stimulus had reached the position of the goal stimulus on the left.

Experiment 2. The procedure was almost the same as in Experiment 1. However, as shown in Figure 2(a), participants had to keep gazing at the focus point “+” presented at the center of the screen. This procedure made it impossible for pursuit eye movement to track the moving target stimulus in central vision.

Experiment 3. The procedure was almost the same as in Experiment 1. However, as shown in Figure 2(b), participants had to count the number of line drawings in the Chinese character presented in the center of the screen. The purpose of this procedure was to significantly reduce the attentional resources allocated to the target stimulus. Similar to the dual tasks imposed on participants in Takano, et al. (2015) and Furuki, et al. (2012), the task of counting utilized a large portion of the participants’ short-term memory, but little long-term

memory. The number of line drawings in the Chinese character was 13 to 14, a number sufficiently high to count to, thus exceeding the time required for the target stimulus to reach the goal stimulus. Participants were instructed to count the number of line drawings mentally, not to count it using their fingers, so that they would be able to press the mouse button.

Data Analysis

Data collection and analysis were conducted to verify the following two points:

Accuracy of motion prediction. Data were collected as *time error*, by calculating the absolute difference (in ms) between the time it took the target stimulus to reach the goal stimulus on the left and the moment when the participant pressed the mouse button, as in Figure 1. In order to verify the effects of the presence or absence of pursuit eye movement and allocation of attention, a factor analysis of variance, and later multiple comparisons through a t-test between Experiments 1 and 2, and Experiments 2 and 3, respectively were done.

Tendency towards early or delayed reactions. A minus or plus value of the above time error signifies an early or delayed reaction, respectively. The significance of an early or delayed reaction compared to the correct reaction was verified by a t-test, as to whether the mean value at each experiment was significantly different from the reaction time error of 0ms.

Result

Figure 3 shows the mean and standard deviation of the time error ($n = 10$). The time error was larger in Experiment 2 than in Experiment 1, and larger in Experiment 3 than in Experiment 2. The result of the factor analysis of variance indicated that the effect of different experimental conditions was significant ($F(2, 18) = 16.0, p < 0.001$). The result of multiple comparisons indicated that there was a significant difference at the 5% level between Experiments 1 and 2, and between Experiments 2 and 3.

Figure 3. The mean and standard deviation of the time error in each experiment.

Table 1 shows the mean and standard deviation of minus and plus time errors when participants had early and delayed reactions, respectively. The mean indicated that there was a tendency for participants' reactions to be slightly early in Experiment 1, slightly delayed in Experiment 2, and very delayed in Experiment 3. The standard deviation tended to be larger in Experiment 2 than in Experiment 1, and larger in Experiment 3 than in Experiment 2. Comparing the time error of each experiment with the time error value of 0 ms at the t-test, the

result indicated that there were no significant differences in Experiment 1 ($t = 1.90$, n.s.) and Experiment 2 ($t = 0.54$, n.s.). However, a significant difference was observed in Experiment 3 ($t = 2.42$, $p < 0.05$).

Table 1

The Mean and Standard Deviation of the Minus or Plus Time Error (in ms) and the Result of the T-Test

	Exp. 1	Exp. 2	Exp. 3
Mean	-55	23	162
SD	91	135	211
T-test	n.s.	n.s.	$p < 0.05$

Discussion

To examine the effect of pursuit eye movement and attention, the results between Experiments 1 and 2, and between Experiments 2 and 3, respectively, are compared below.

Experiments 1 vs. 2

A comparison of the results of Experiments 1 and 2 indicated that pursuit eye movement on the target stimulus is important for predicting perceptual motion accurately. By tracking the moving position of the target stimulus in real time in central vision, the moment in time at which the target stimulus reaches the goal stimulus can be predicted with better accuracy. On the contrary, if pursuit eye movement is not possible, then the position of the target stimulus is predicted in real time by the internal pursuit in peripheral vision, but the accuracy in SART decreases. As shown in Table 1, there was no significant tendency towards either early or delayed reactions in Experiment 2. These results indicate that internal pursuit with no eye movement causes a general decrease in accuracy to predict perceptual motion without any bias towards an early or delayed reaction.

In Nakazono and Kobori (2008), the time error increased significantly when the goal stimulus disappeared halfway, even if it had up till then been followed with pursuit eye movement. If the goal stimulus would disappear halfway in the present Experiment 2, it is anticipated that it becomes more difficult to accurately predict the position of the target stimulus with internal pursuit in peripheral vision.

Mimura and Fujita (2018) pointed out that drivers need the ability to continuously and appropriately exchange visual attention resources between observing specific objects in a “narrow and deep” manner, and observing multiple objects in a “wide and shallow” manner in the entire field of view. It is usually necessary to process many visual objects while driving. This means that while a specific object is observed narrowly and deeply, information on other objects is detected in peripheral vision. Visual information around the gaze point, which is grasped specifically in the useful field of view (UFV), is important to be instantly stored and retrieved during the visual task. The UFV is a narrow region around the center of vision and becomes smaller with aging. The level of accuracy measured in SART of peripheral vision in Experiment 2 witnessed a decrease from the measure of central vision in Experiment 1. The results of these experiments indicate that it is not only the accurate visual cognitive ability in central vision but also the cognitive function of UFV and peripheral vision that is important for safe driving.

Experiments 2 vs. 3

In both Experiments 2 and 3, participants could not make pursuit eye movement to follow the moving target stimulus and therefore had to predict its position in peripheral vision. The difference between the two

experiments was the distribution of attention onto the target stimulus. Full attention was allocated to the target stimulus in Experiment 2. However, there was little attention given to the target in Experiment 3 because much of it was allocated to the task of counting the number of line drawings. A comparison of these results shows that the predictive accuracy of perceptual motion decreases greatly if attention is not allocated to the target stimulus with internal pursuit in peripheral vision. Furthermore, as shown in Table 1, a significant tendency towards a delayed reaction was observed in Experiment 3. It can be interpreted that an allocation of attention towards a counting task would cause a delay of reaction in determining speed accruals, and consequently the accuracy of predicting perceptual motion decreases.

Applying the results of this research to driving, if we look at other objects like car navigation systems, the capacity of working memory is used for processing its information. As a result, reactions to visual information perceived in peripheral vision, which should receive a greater portion of attentional allocation, become inaccurate. There is a tendency towards delayed reactions occurring in such situations. Another example of a situation that uses the capacity of working memory while driving is watching TVs, smart phones, and other such devices. In these cases, since the driver is not only viewing the object but also operating it using a hand or arm, the perception of visual information in peripheral vision is even more inaccurate or delayed. It is important to limit the amount of visual information to what is necessary for carrying out driving operations when we drive.

The task that required counting the number of line drawings in the Chinese character involved short term memory processing as well as the faculty for carrying out a mental arithmetic task. In Takano, et al. (2015), the time error of the response increased in the *Shiritori* task that used long-term memory than in the mental calculation task that used short-term memory. Similarly, in the present SART, it can be assumed that the time error becomes larger in cases of dual tasks that require long-term memory. For example, this is the case when participants are to reminisce on their own memories while the target stimulus is moving. In the case of driving, it is assumed that thinking about things other than what is necessary for driving, such as work, home, problems in life, etc., will result in inaccurate driving reactions. While driving, it is important to not access one's long-term memory of various events that have occurred outside of the car, but concentrate on processing information that is necessary for driving.

Conclusion

The results in the present experiments have shown that pursuit eye movements that track a target stimulus in central vision, or the allocation of attention with internal pursuit towards a target stimulus in peripheral vision, become important for accurate speed accrual. In order to accurately perceive visual information while driving, it is important for the driver to use pursuit eye movements to follow the motion of visual objects in central vision, and to use internal pursuit to follow objects not gazed at directly central vision, but with sufficient attention given to peripheral vision.

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