

Effects of State of Eye Movements before Saccade on Efficiency of Response to Stimulus - Comparison of Search Efficiency between Fixation and Smooth Pursuit Situations -

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Abstract— In this study, how the state of eye movement before saccade affected the response to a stimulus was explored. The state of eye movement before saccade was either smooth pursuit or fixation. The smooth pursuit was carried out both clockwise and counter-clockwise. Using an eye-tracking system, the eye movement during the experimental task was monitored. The response time to a stimulus was measured. On the basis of the eye movement data (coordinate), the eye movement velocity, the eye movement acceleration, and the latency of eye movement were obtained. When smooth pursuit was carried out before saccade, the response to a stimulus which appears as a result of saccade was faster. More concretely, the response time of smooth pursuit condition was faster than that of fixation condition. The latency of the smooth pursuit condition tended to be faster than that of the fixation condition. Some implications for the application of the results to the traffic safety or automotive ergonomics were given.

1. Introduction

In our daily life, the retrieval of information is essential. Without this activity, nothing can be performed. In a standard visual search task, the search activities are typically evaluated using reaction times, that is, the time to find an object. Instead of checking how many objects are inspected in a search display and the time spent looking at each of these objects, reaction time is convenient in that it compresses such activities into a single variable. If the search time of one task is longer than that of another task, we judge that one task is more difficult than another. If we want to understand what kind of cognitive activities is happening during visual search, reaction time seems less suited for this purpose. As search is highly complex cognitive behavior that has both a spatial and a temporal component, it is difficult for this measure to reveal how the search process progresses over time.

Althoff et al.^[1] examined an eye-movement-based memory effect and showed different patterns of eye movement elicited by famous and non-famous faces. They concluded that the eye-movement-based memory effect is the expected consequence of previous exposure to famous faces. Donk^[2] investigated human monitoring behavior in a multiple-instrument setting and showed that the spatial arrangements of the instruments on the display affected sampling behavior. He also found that human monitoring seemed to be biased by a tendency towards sampling by means of horizontal transitions at the cost of diagonal transitions. Rayner^[3] suggested that the basic mechanism of eye movement control is similar

across tasks (reading, scene perception, visual search, etc.), but that the trigger to move the eyes is different according to the specificity of the tasks. It has been suggested that eye movements should be used to study visual search. Actually, several studies have paid attention to the number of saccades occurring during search and their fixation durations (Gould and Dill^[4]; Luria and Strauss^[5]; Engel^[6]; Megaw and Richardson^[7]; Scinto, Pillalamarri, and Karsh^[8]). Thus, eye movement characteristics are useful to investigate a variety of cognitive process by decomposing search into spatial and temporal components.

Voluntary jump from one fixation to another referred to as saccadic eye movement. These movements are fast and characterized by a high initial acceleration and a high final deceleration. The main function of saccade is to change the point of fixation and to direct the most sensitive region of retina (fovea) to a particular element of the object of perception. The high velocity of saccade and correspondingly short duration of saccades usually permit the eye to remain in a state of fixation (See Stein et al.^[9], Yarbus^[10]). The high velocity of saccade leads to blurring of an object within the field of view. It seems that during the saccade no visual images are formed but that the eye does not lose its perceptive power.

There are many studies which explored the relationship between saccade eye movement and attention^{[11]-[18]}. Kowler^[13] showed that the percentage correct stimulus discrimination is larger when the stimulus was presented to a location where saccadic eye movements end than the stimulus was presented to other locations. Schneider et al.^[17] showed that the performance of target (stimulus) discrimination was better when saccadic eye movement was directed to a target located more foveally of the discrimination target than when the saccadic target was located more peripherally.

However, the effects of the state of eye movement before saccade on the response to a stimulus after the saccadic eye movement have not been paid attention to. In driving situations, a few automotive manufactures have put a pedestrian detection system such as Night vision or Eyesight to practical use to reduce the accident during the night. In these practical applications, the loss of visual information processing when the attention is moved towards the pedestrian detection display is not systematically explored. When the driver is paying attention to the central road situation and the pedestrian detection system suddenly detects the pedestrian, the driver must make saccadic eye movements to pay attention to the detected result.

During saccadic eye movement, information

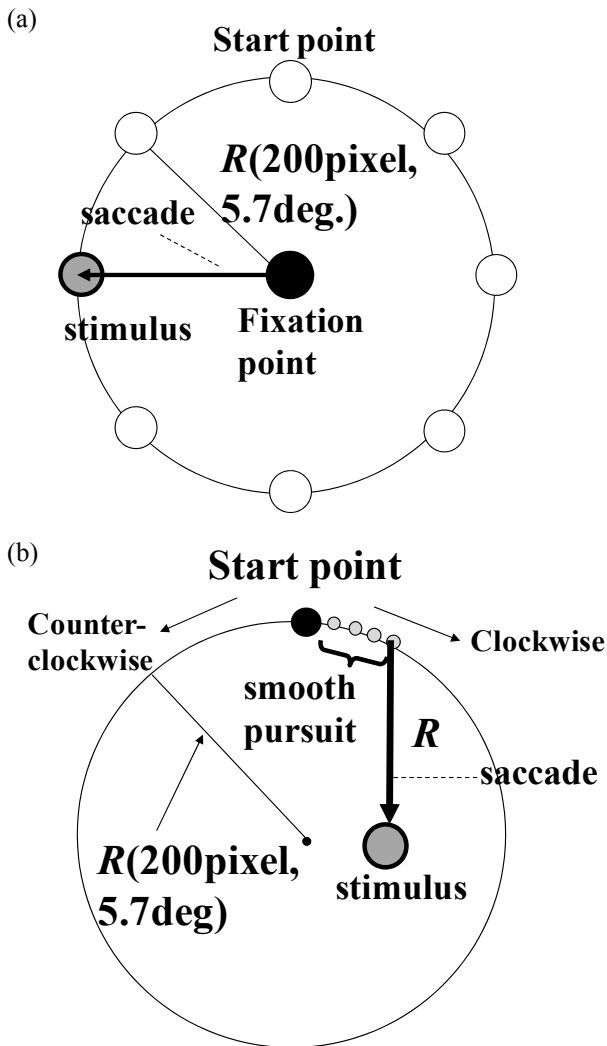


Fig.1 The experimental displays. (a) the state of eye fixation before saccadic eye movement occurs, (b) the situation where smooth pursuit eye movement takes place before saccadic eye movement occurs

processing is suppressed [12]-[14]. Therefore, a system where saccade suppression does not occur is desirable. Although the pedestrian detection system seems to be appealing from the viewpoint of safe driving, such a system must be developed on the basis of the ergonomic data or findings such as the placement of pedestrian detection display or an effective method for avoiding saccadic depression.

On the basis of the discussion above, how the state of eye movement before saccade affects the response to a stimulus after saccade (for example, using saccadic eye movement and responding quickly to avoid dangerous situation concerned with pedestrian) must be basically explored. In this study, we assumed that the state (smooth pursuit or fixation) before saccadic eye movement might have some effects on the response to a stimulus after the saccadic eye movement. If such a factor affects the response to some target after saccade, we must take this into account in order to enhance the safety during driving.

In this study, how the state of eye movement before saccade affected the response to a stimulus was explored. The state of eye movement before saccade was either smooth pursuit or fixation. The smooth pursuit was

carried out both clockwise and counter-clockwise. Using an eye-tracking system, the eye movement during the experimental task was monitored. The response time to a stimulus was measured. On the basis of the eye movement data (coordinate), the eye movement velocity, the eye movement acceleration, and the latency of eye movement were obtained.

2. Method

2.1 Participants

Ten participants from 21 to 23 years (average: 21.8 years) took part in the experiment. All were male. The visual acuity of the participants in both young and older groups was matched and more than 20/20. They had no orthopedic or neurological diseases.

2.2 Apparatus

An eye-tracking device (EMR-VOXER, Nac Image Technology) was used to measure eye movements characteristics during the search task. This apparatus enables us to determine eye movements and fixation by measuring the reflection of low-level infrared light (800 nm), and also admits the head movements within a predetermined range.

The eye-tracker was connected with a personal computer (HP, DX5150MT) with a 15-inch (303mm x 231mm) CRT. The resolution was 1024 x 768 pixels. Another personal computer was also connected to the eye-tracker via a RS232C port to develop an eye-gaze input system. The line of gaze, via a Rs232C port, is output to this computer with a sampling frequency of 60Hz. The illumination on the keyboard of a personal was about 200lx, and the mean brightness of 5 points (four edges and a center) on CRT was about 100cd/m². The viewing distance was about 70 cm.

2.3 Task

The experimental displays as shown in Fig. 1(a) and (b) were prepared. Fig.1(a) corresponds to the state of eye fixation before saccadic eye movement occurs. Fig.(b) corresponds to the situation where smooth pursuit eye movement takes place before saccadic eye movement occurs.

In Fig.1(a), the participant was required to gaze at (fixate) the central fixation point. After 5 to 10 s, the target stimulus appears randomly at one of eight directions of the circle of radius R. The participant was required to make a saccadic eye movement to this target and response using a space bar of the keyboard as soon as possible.

In Fig.1(b), the participant was first required to make a smooth pursuit clockwise or counterclockwise. Then, the target stimulus appeared at a location which is by R apart from the location at present. The participant was required to fixate (gaze at) the target by saccadic eye movement and response using a space bar of the keyboard as soon as possible.

2.4 Design and procedure

The experimental factors were the state of eye movement before a saccadic eye movement occurs ((a) fixation condition or (b) smooth pursuit condition) and the direction of saccadic eye movement (eight directions: upper, lower, right, left, upper right, upper left, lower right, lower left). These corresponded to within-subjects factors. The order of performance of (a) and (b) was randomized across the participants.

In one session, eight trials were carried out, and target appeared randomly at one of eight directions above. This session was repeated five times. Whether the participant made a saccade or not was monitored by an eye-tracking system. This was similar to both (a) fixation

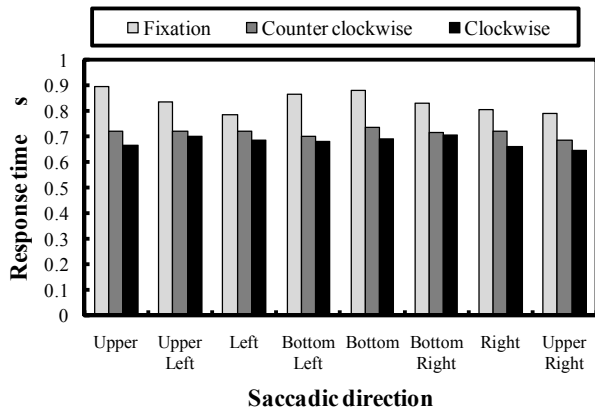


Fig.2 Response time as a function of state before saccade and saccadic direction.

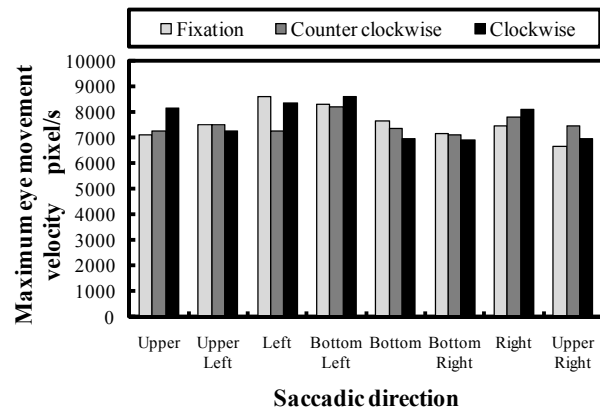


Fig.4 Maximum eye movement velocity as a function of state before saccade and saccadic direction.

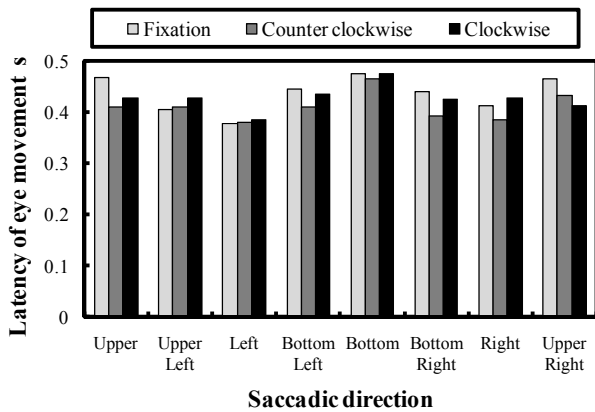


Fig.3 Latency of eye movement as a function of state before saccade and saccadic direction.

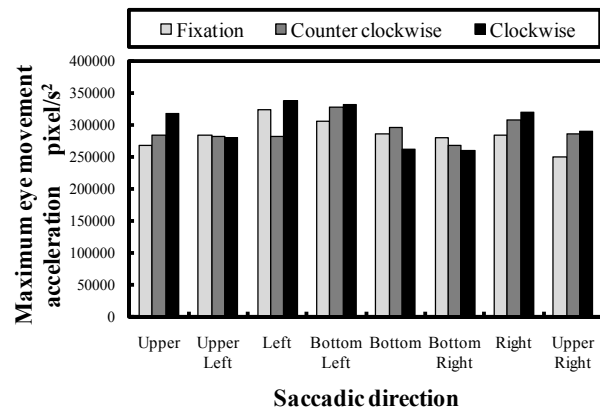


Fig.5 Maximum eye movement acceleration as a function of state before saccade and saccadic direction.

condition and (b) smooth pursuit condition.

The response time (time from the target appearance until the saccadic eye movement to the target and press of space bar) was measured. The eye movement parameters were also obtained on the basis of the eye-tracker coordinates obtained every 1/60 s. The following measures were used.

- (A) Response time
- (B) Latency of eye movement
- (C) Maximum eye movement velocity
- (D) Maximum eye movement acceleration

3. Results

A two-way (state before saccade and saccadic direction) ANOVA was carried out on the measures (A) above. As a result, only a significant main effect of state before saccade ($F(2,18)=10.191, p<0.01$) was detected. A Fisher's PLSD (Protected Least Significant Difference) multiple comparisons revealed significant ($p<0.01$) differences between fixation and clockwise smooth pursuit, and between fixation and counterclockwise smooth pursuit). A similar two-way ANOVA conducted on (B) latency revealed only a significant main effect of saccadic direction ($F(7, 63)=3.926, p<0.01$). As a result of a similar two-way ANOVA conducted on (C) maximum eye movement velocity, no significant main effect of saccadic direction was detected. No significant state before saccade by saccadic direction interaction was also detected. A similar two-way ANOVA conducted on (D) maximum

eye movement acceleration, no revealed no significant main effect of saccadic direction and no significant state before saccade by saccadic direction interaction.

In Fig.2, the response time is plotted as a function of state before saccade and saccadic direction. In Fig.3, the latency is plotted as a function of state before saccade and saccadic direction. The maximum eye movement velocity and acceleration are shown as a function of state before saccade and saccadic direction in Fig.4 and Fig.5, respectively.

In order to examine the difference of evaluation measures (A)-(D) between clockwise and counter clockwise smooth pursuit conditions, a two-way (smooth pursuit direction by saccadic direction) ANOVA was carried out on the measures (A)-(D). As a result of such a two-way ANOVA, no significant main effects and an interaction were detected for all measures (A)-(D).

4. Discussion

When smooth pursuit was carried out before saccade, the response to a stimulus which appears as a result of saccade was faster. More concretely, the response time of smooth pursuit condition was faster than that of fixation condition (Fig.2). Although a statistically significant difference was not detected, the latency of the smooth pursuit condition tended to be faster than that of the fixation condition (Fig.3). As a whole, eye movement-related parameters such as latency, maximum velocity, and maximum acceleration did not differ irrespective of the state before saccade was carried out. This might

mean that the state before saccadic eye movement does not affect perceptual process. Whether the participant fixated or pursued smoothly before saccadic eye movement seem to affect the response to a target to which eye movement was moved by saccade. The state of eye movement before saccade did not affect perceptual process, but it affected the later cognitive process and lead to faster response. In other words, the smooth pursuit might lead to faster processing after perceptual process.

The effects of direction of smooth pursuit eye movement are discussed. As shown in Fig.2-Fig.5, there seems to be no significant difference of Measures (A)-(D) between clockwise and counterclockwise eye movements.

The effects of location of saccade on the parameters are discussed. The location of saccade affected latency (See Fig.3). The latency when the saccade was carried out to the left upper direction tended to be lower especially for the clockwise pursuit eye movement. This was true for other states (counterclockwise smooth pursuit and fixation). Moreover, the latency of the saccade to the left tended to be shorter than that to the right. Direction of saccade seems to affect the ease with which the saccadic eye movements are undertaken.

In summary, the processing after perceptual process is promoted when smooth pursuit was carried out before saccade than when fixated before saccade. The location of the saccade seems to affect eye movement characteristics, especially latency. The saccadic eye movement to the left seem to promote quick onset of eye movement (saccade) than that to the right.

Some implications and potential applications for traffic safety and automotive ergonomics shall be given. Until now, the effects of the state of eye movement before saccade on the response to a stimulus after the saccadic eye movement have not been paid attention to. In driving situations, a few automotive manufactures have put a pedestrian detection system such as Night vision or Eyesight to practical use in order to reduce accidents due to the missing of a pedestrian during the night. When the driver is paying attention to the central road situation and the pedestrian detection system suddenly detects the pedestrian, the driver must make saccadic eye movements to pay attention to the detected result. It is pointed out that information processing during saccade is suppressed^{[12]-[14]}. In these practical applications of pedestrian detection system, the suppression of visual information processing when the attention is moved towards the pedestrian detection display during saccadic eye movement has not systematically been explored.

During saccadic eye movement, information processing is suppressed^{[12]-[14]}. Therefore, a system where saccade suppression does not occur should be developed. Although the pedestrian detection system seems to be appealing from the viewpoint of safety driving, such a system must be developed on the basis of the ergonomic data or findings such as the placement of pedestrian detection display or an effective method for avoiding saccadic depression.

On the basis of the discussion above, how the state of eye movement before saccade affects the response to a stimulus after saccade (for example, using saccadic eye movement and responding quickly to avoid dangerous situation concerned with pedestrian) must be basically explored.

In this study, we assumed that the state (smooth pursuit or fixation) before saccadic eye movement might have some effects on the response to a stimulus after the

saccadic eye movement. If such a factor affects the response to some target after saccade, we must take this into account in order to enhance the safety during driving. As pointed out in this study, the state of eye movement before the saccade affects the response, and the location of saccade also affects the ease with which the onset of eye movement is performed. The results should be taken into account and incorporated into the design of pedestrian detection system.

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