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INVESTIGATION OF THE BLINKING CONTINGENT UPON SACCADIC EYE MOVEMENT[1]

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The blinking contingent on saccadic eye movement (BCE) was studied experimentally. It was found that, when the BCE was evoked, its onset always preceded that of the contingent eye movement about 90 msec, and its durations ranged from 350 msec to 400 msec. The frequency of BCEs became higher in proportion to the increase in the angular size of the eye movement. In the experiment in which blur was produced on retinal image by eye movement, we found that the BCE occured more frequently in the strong-blur condition than in the weak-blur condition.

It is worth while to notice that there are several similarities between the BCE and saccadic suppression, such as the temporal property and the relation with the angular size of eye movement. The present results suggest that the BCE may take an assistant part in cutting off the blur of retinal image.

INTRODUCTION

The frequency of involuntary blinks varies with some external or internal conditions. It has been made clear that the moistening of the cornea is not an important factor by the classical study of Ponder and Kennedy (1927).

As a factor affecting the blink rate the fatigue of the eyes caused by visual circumstances was also investigated. Some researchers reported an inverse relation between the frequency of blinks and the adequacy of visual circumstances (such as levels of illumination), while other could not find such a relation (see Luckiesh & Moss, 1937 or Tinker, 1949).

Holland and Tarlow (1972) examined the relation between the blink rate during memorizing task and the mental load provided by the task. They concluded that the inhibition of blinking when the mental load increased might be an adaptive mechanism which protected the vulnerable cognitive process from any possible interference produced by blinking. In the same way, it was said that blink occured at a pause of

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1. This paper is based on the graduation thesis of T. Fujita who carried out the experiments reported here. J. Gyoba suggested the thesis and assisted him in the accomplishment of the experimental methods. Y. Watanabe made a critical reading of the thesis and prepared this manuscript. And they wish to express gratitude to Dr. H. Tada of Fukushima Medical College for the recommending of the related papers.

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the tracking task and its redundant part (Drew, 1951). Hall (1945) investigated similar blinks which occurred at the punctuation marks or at the ends of sentences or at the time to turn a page. He considered these blinks as a technique acquired in training.

Although it has not been fully explained how mental load takes part in visual information processing, blinks have been considered as the noise for effective performance in this context. For example, Broadbent[3] mentioned that blink cut off the incoming visual information to the nervous system instantaneously in the same way as the noise impinging in a communication channel, so that a man has to control the timing of his blinks.

But there have been several views taking the function of blinking as positive. Hall (1945) has already reported that there were many blinks at the direction changes of fixation. Von Cranach et al. (1969) studied experimentally the blinking contingent upon saccadic eye movement (hereafter, BCE in abbreviation). They found the frequency of BCE became higher in proportion to the increase in the angular size of the eye movement. And the frequency of BCE was generally higher in the head-free condition than in the head-fixed one. They referred the hypothesis that the function of BCE was to keep off the motion of retinal image. But they did not strictly examine the temporal property of BCE which seems indispensable for the discussion of the contingency.

To examine their hypothesis more intensively, we carried out the following three experiments.

Experiment I

The purpose of the first experiment was to measure the temporal characteristics of BCE.

Subjects: Two male undergraduates of Tohoku university participated in the experiment. Throughout the experiments reported in this paper, the subjects were naive as to the measurement of blinking and were told that the purpose of the experiment was to record eye movements in the required task.

Stimulus display: The experiment was conducted in a sound proof and shielded room. A chair for the subject was enclosed semi-circularly with the display board (90 cm in height, 180 cm in length and 70 cm in radius). In the middle height of this display board, 15 LEDs were located horizontally at intervals of 10° in visual angle. The height of these targets was adjusted for each subject's eye-level. The central LED used as a fixation point was green, while the other peripheral LEDs were red. The display board was black. Switching of these LEDs was controlled with the timer of tachistoscope (TKK TR-6). The subject was to be seated on the chair and his head was not fixed.

Recording apparatus: The cornea-reflex method was used supplementally, in addition to the polygraphic recording, because the polygraphic recording of blinking contains

3. Broadbent, D.E. 1958 *Perception and Communication.* London: Pergamon Press, pp-96.

some confusing wave patterns. We considered the disappearance of the cornea-reflex image caused by shuttings of the eyelids as the indicator of blinking. The temporal resolutionability of the TV-video system used in the cornea-reflex method reached to 1/60 sec, so the comparison between the cornea-reflex image and the polygraphic recording seemed to be available enough.

An electro-encephalograph (NIHON KODEN ME 1350) was employed for the polygraphic recording. The subject's blink was measured as EMG from bipolar electrodes attached above and beneath the right eye. Time constants selected in recording were 0.05 sec. For horizontal eye movements, EOG was recorded from the electrodes applied at outer margin of each eye with time constant 4.0 sec. The reference electrode was fixed on the earlobe.

A head-mounted cornea-reflex camera (NAC Eye-Mark Recorder, Model IV) and video-recording system (SONY AV 3750) were employed for monitoring the cornea reflex image. These systems and the other TV-camera which recorded the display of a digital timer were synchronized together with the polygraphic recording.

Procedure: In Experiment I, the display was limited to 7 LEDs within 30° on both sides of the fixation point. The LEDs were switched so as to light the center first and one of 6 peripheral LEDs and finally the center again. The peripheral target LED was randomly chosen and its duration was changed randomly within 1 sec, 2 sec or 3 sec in order to avoid the regularity of stimulus presentation. The task of the subject was to change his fixation toward the target LED as soon as he detect its lighting.

Results

When the subject changed his fixation from the center to periphery, the BCE scarcely occured. We considered this was due to some tension, which might be a mental load of the subject caused by the required task. Therefore, we were to examine the blinks contingent upon the second eye movement which was started from periphery to center. This procedure was common throughout the following experiments.

The temporal properties of BCE were examined from the polygraphic recordings whose accuracy was guaranteed by the cornea-reflex method. Twelve BCEs were analyzed in each subject. In analysis, the size of the eye movements was counted-out.

When the BCE occurred, the onset of BCE always preceded that of the eye movement. These preceding-times of BCEs in the two subjects are shown in Table 1. The average over these times was about 90 msec. A typical polygraphic recording is shown in Fig. 1. The disappearance durations of the cornea-reflex image caused by the BCE ranged from 350 msec to 400 msec, of course these durations were much longer than the movement time of saccadic eye movements. According to this examined temporal property, the BCE occurred so as to cover the saccadic eye movement wholly.

Table 1. The times the BCE preceded the eye movement (in msec).

Subject	Preceding-times in each BCE												
	1	2	3	4	5	6	7	8	9	10	11	12	Mean
A	130	100	80	70	150	80	100	250	120	50	150	80	113.3
B	67	80	67	60	80	0	77	60	53	67	50	73	61.2

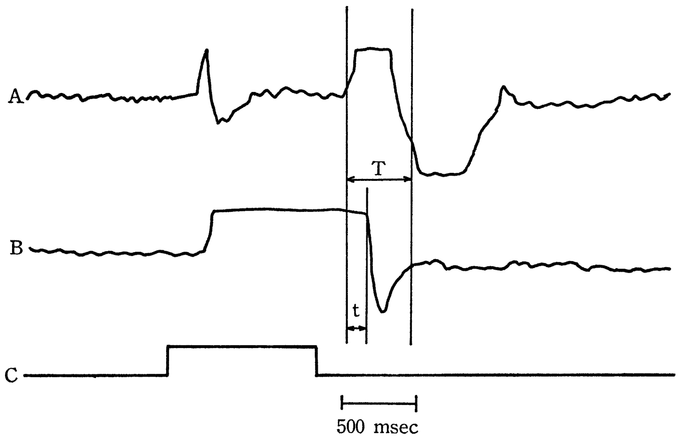

Fig. 1. Polygraphic recording of a typical BCE.
A: EMG recording of blinking. B: EOG recording of eye movement. C: The temporal course of the peripheral LED's lighting. T: The duration of the disappearance of the cornea-reflex image caused by the blinking. t: The time the BCE preceded the saccadic eye movement.

Experiment II

The purpose of the second experiment was to confirm the relation between the frequency of BCE and the angular size of the eye movement. Another purpose was to examine the effect of the mental load on the frequency of BCE, because we considered that the inhibition of blinking at the first eye movement in Experiment I was due to possible mental load involved in the task required.

Method

Subjects: Subjects were twelve undergraduate students (6 males, 6 females).

Apparatus: The stimulus display was the same as that of Exp. I, but the target LEDs were limited to those at 10°, 30° and 50° on both sides. Recording system was the polygraphic one only, because the experimenter had become skilled through the pre-examination and Exp. I in discriminating the waves of blinks from other confusing patterns. Time constants of EMG and of EOG were the same as those of Exp. I.

Procedure: The frequency of BCE in the task in which the subject was asked to change his fixation was measured in the following two conditions.

(1) Guided condition: The LEDs were switched in the same order as that of Exp. I, namely center-periphery-center. The subject had to return his fixation to the center from periphery as soon as he detect the central LED lighting.

(2) Optional condition: The central LED was lighted first and one of the peripheral LEDs was lighted, but the central LED was not lighted again. The subject was to return spontaneously his fixation to center at his optional timing.

If it would provide the subjects with any mental load to change his fixation as soon as he detected the central target lighting, the frequency of BCE was supposed to be less in the guided condition than the optional condition. The same subject was tested under the two conditions in counter-balanced order. The other details of procedure were the same as those of Exp. I.

Results

Saccadic eye movements were produced 10 times for each target located at 10°, 30° and 50° on each side of the fixation point. Thus, total 120 eye movements were recorded from each subject. The average frequencies of BCE over 12 subjects under each experimental condition are depicted in Fig. 2 as a function of the angular size of eye movements.

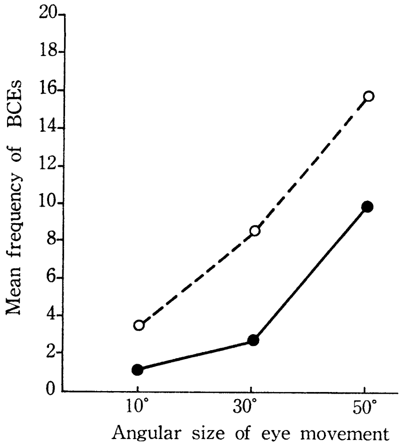

Fig. 2. The mean frequencies of BCEs over twelve subjects, as a function of the angular size of eye movement for two experimental conditions (●–●: Guided condition, ○–○: Optional condition).

The frequency of BCE increases in proportion to the increase in the size of eye movement. And the frequency of BCE in the optional condition is generally higher than in the guided condition.

From an analysis of variance, the main effect of the experimental conditions was found significant ($F=14.60$, $df=1/11$, $p<0.01$). The main effect of the angular size of eye movement was also significant ($F=55.94$, $df=2/22$, $p<0.01$). The interaction of these effects was not significant ($F=3.15$, $df=2/22$ $p>0.05$).

Experiment III

Although the frequency of BCE was two times higher in the optional condition than in the guided condition in the previous experiment, it seems difficult to explain these results only with mental load. Because it is not acceptable that the effect of mental load represents such a systematic change according to the size of eye movement as observed. Even if the inhibition of BCE would be caused by some mental load, it seems probable that the detection task of targets provides higher mental load rather at larger eye movement and the BCE should be elicited less frequently. However the reverse is the case.

Here, the perviously mentioned hypothesis by Von Cranach et al. seems to be worth while to consider. Yoshimura (1976) examined the BCE under the hypothesis that its function is to cut off the motion of retinal image for the stability of the visual space. But he could not find a clear result which supported his hypothesis.

When we consider the function in cutting off the blur of the retinal image when the eyes move, we must take notice of saccadic suppression, as Yoshimura has mentioned. There have been many studies about saccadic suppression. Although there are several discordances in detail, it is generally said that the decrease in sensitivity by saccadic suppression is from approximately 0.5 to 1.5 log unit and that its duration precedes eye movement in about 50 msec and outlasts about 150 msec (Matin, 1975; Nakamizo, 1975).

It is worth while to notice that the temporal property of BCE which we obtained in Exp. I was similar to that of saccadic suppression. Moreover, an article says that the strength of saccadic suppression also increases with the angular size of eye movement (Mitrani et al., 1970). Are these correspondences only coincidental ones ?

In this experiment we investigated the BCE under the hypothesis that the frequency of BCE would increase at a visual display with many visual components, because such a display was expected to produce a strong blur on the retinal image.

Method

Subjects: Twelve undergraduate students (6 males and 6 females) who did not serve in the previous experiment.

Apparatus: A string of random alphabet letters was attached below the target LEDs. These letters were made of instant-lettering patterns whose height was 30 mm and width was about 22 mm. The targets were 14 LEDs located at 10°, 20°, 30°, 40°, 50°, 60° and 70° in visual angle on both sides. The recording system was almost the same as that of Exp. II.

Procedure: The task of the subject was fundamentally the same as that of the optional condition in the previous experiment. The subject was asked to detect the peripheral target's lighting by changing his fixation and to return his fixation spontaneously to center after the detection. The following three conditions were provided in this task.

(1) Strong blur condition: The interval between the centers of neighboring letters was arranged to be 2° in visual angle, so there were total 71 letters on the display board.

(2) Weak blur condition: The letters were presented at the interval of 10°, so there were only 15 letters on the display board.

(3) Least blur condition: No letter was presented. And the experimental room was darkened.

In the experimental conditions (1) and (2), the subject was asked to report verbally the letter beneath the target. In condition (3), the subject had only to change his fixation following the target.

Each condition had a block of 70 trials in which the target was chosen randomly amoung 14 peripheral LEDs so that each target might be presented 5 times. The duration of target was changed randomly within 2, 2.5 and 3 sec, because the regularity of stimulus presentation would cause a blinking at the fixed pause. A subject was tested under three experimental conditions and its order was counter-balanced among the subjects.

RESULTS

The frequency of BCEs was measured in ten eye movements for each of 7 angles of targets. The mean frequencies of BCEs under each experimental condition are shown in Figur 3 as a function of the angular size of eye movement.

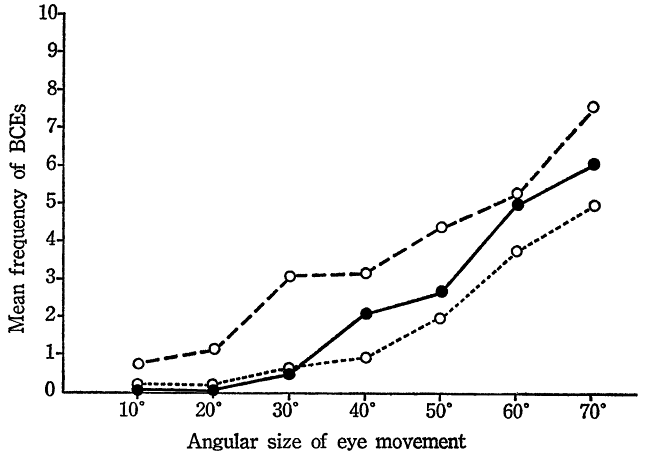

Fig. 3. The mean frequencies of BCEs over twelve subjects, as a function of the angular size of eye movement for three experimental conditions (●—●: Strong blur condition, ○----○: Weak blur condition, ○– – –○: Least blur condition).

From a three-way analysis of variance, we found the main effect of the eye movement angle was significant ($F=26.25$ $df=6/66$ $p<0.01$). The main effect of the blur difference was also significant ($F=14.75$ $df=2/22$ $p<0.01$). The interaction of these effects was not significant ($F=1.75$ $df=12/132$ $p>0.05$).

The frequency of BCE becomes higher in proportion to the increase in the angular size of eye movements in all experimental conditions.

As for the experimental conditions of the blur, the frequency of BCE is the highest in the least blur condition. We interpret this unexpected result as due to the intervention of the mental load. The mental load in the condition (3) might be less than the others, because subjects had no additional tasks to identify and to report verbally the letter.

Although the difference between the conditions (1) and (2) was not statistically significant according to a Newman-Keul's test, the strong blur condition seems to produce more BCEs than the weak blur condition, particularly in larger eye movements.

Discussion

The experimental results that we obtained about the BCE are as follows. (1) The BCE preceded and outlasted the saccadic eye movement. (2) The frequency of BCEs increased in proportion to the angular size of eye movement. (3) The frequency of BCEs was higher at the spontaneous eye movement than at the guided eye movement. (4) The BCE tended to be produced when the blur of the retinal image was made stronger.

The occurrence of BCE seems to be affected by the mental load provided to the subject regardless of the size of eye movements. But when we consider such results as the temporal property, the proportional relation with the size of eye movement, and the effect of the visual stimuli, the occurrence of the BCE cannot be explained with the mental load only.

Although there may be a veiw that the friction between the cornea and the eyelids takes a part, it is not directly acceptable because we observed that the BCE preceded the coincidental eye movement.

Then, the previously mentioned similarities between the BCE and saccadic suppression become suggestive. It seems reasonable that the BCE takes some part in cutting off the blur of the retinal image. Of course, the blinking is not always contingent upon the saccadic eye movement. When such mechanisms as saccadic suppression do not operate enough, the blinking may participate in them as a shutter (Richards, 1975)[4].

Some physiological findings provide reasonable supports to this view. The musculus levator palpebrae superioris, which is one of the muscular system concerned with the blinking, is said to be controlled by the oculomotor nervous system. There is an article which reported that the inhibition of pupillary reflex, whose muscular system was also controlled by the oculomotor system, occurred corresponding to saccadic suppression (Zuber, et al., 1966).

Thus, although there has been little work which takes the function of blinking

4. Richards, W. 1975 Visual space perception. In Carterette, E.C. & Friedman, M.P. (eds.), *Handbook of Perception*, Vol V: Seeing, New York: Academic Press, pp–360.

as possitive, the present study suggested some functional similarities between blinking and saccadic suppression. To cut off the blur of the retinal image is one of the fundamental problems in the stability of vision. It is further necessary to reconsider the BCE in the whole oculomotor system concerned with the stability of vision.

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