Changes in blink rate during signal discrimination tasks

KYOSUKE FUKUDA and KATSUYA MATSUNAGA
Department of Psychology, Faculty of Literature, Kyushu University, Higashi-ku, Fukuoka 812

Effects of stimulus modality, information processing activity and motor response on the blink rate were examined. In Experiment 1, visual and auditory stimuli were employed. The blink rate peaked just after a stimulus and then progressively decreased until the next stimulus. The changes in the blink rate were similar for both the visual and the auditory stimulus conditions. In Experiment 2, only auditory stimuli were given to examine the effects of discriminative responses and motor responses on the blink rate. The heights of peaks increased as the processing load increased, while the motor responses had no effect on the post-stimulus peaks. Attention level was used to explain the pre-stimulus attenuation, and processing load to the post-stimulus peaks.

Key words: blink rate, auditory stimulation, visual stimulation, attention, processing of stimuli, motor response.

Three afferent pathways transmit signals for the eye blink reflex, namely, the optic nerve, the trigeminal nerve, and the vestibulo-cochlear nerve (McEwen & Goodner, 1969). Ponder and Kennedy (1927) showed that blinking occurs even when these pathways are blocked. They observed a normal blink rate in a blind man whose optic nerves were atrophied and whose eyes had been anesthetized. Evidently, blinking serves to do more than just protect the eyes.

The blink rate attenuates in the foreperiod of simple reaction time (RT) tasks (Obrist, Webb, & Sutterer, 1969; Webb & Obrist, 1970; Obrist, Webb, Sutterer, & Howard, 1970). It increases just after warning stimuli and just after task completion (Weerts & Lang, 1973). In the above studies, however, the blink rate was treated only incidentally. The factors directly influencing the occurrence of blinking have not been examined.

Since blinking interrupts visual perception, people inhibit it when they want to see better (Lawson, 1948; Broadbent, 1958). Assuming that blinking does not interrupt auditory perception, one would expect the inhibition and the facilitation of blinking to be different between visual and auditory tasks.

Blinking is facilitated by simultaneous activity in neighboring motor channels (Meyer, 1953). Kornhuber and Deecke reported the appearance on the human scalp of a “slowly increasing surface-negative cortical potential of 10-15 µV” which begins to rise .5 to 1.0 s before voluntary spontaneous hand or foot movement and peaks at the time of response (Tecce, 1972). The facilitation of blinking seems to be related to motor response (MR), because the blink rate also decreases before MR in RT tasks (Obrist et al., 1969). Therefore, this investigation aimed to examine the effect of MR and stimulus modality on the blink rate. It was suggested that the discriminative response influenced the blink rate. In a second experiment, whether or not discriminative responses to be closely related to the peaks of post-stimulus blink rate was investigated.

1 The authors wish to express their gratitude to Professor Takayuki Funatsu of Kyushu University for his advice throughout this research and to Mr. Douglas D. Smylie, Lecturer in American Literature, Kyushu University for his comments and corrections.

Requests for reprints should be sent to Kyosuke Fukuda.
Blink rate during signal discrimination

Experiment 1

Since blinking interrupts visual perception, but presumably has no effect on auditory perception, it follows that visual discrimination tasks should inhibit blinking, and auditory discrimination tasks should not. Experiment 1 tested this hypothesis.

Method

Subjects. The subjects were five graduate students. Post-experimental interviews indicated that none were aware that their eyeblinks were being studied.

Apparatus for presenting stimuli. For the visual stimuli, a red light-emitting-diode (LED) and a green LED were attached to a black screen two meters in front of the subject. The LEDs were placed one centimeter apart, the red on the left and the green on the right. Each had a light intensity of 4 cd/m² and was connected by a sound relay to the tape recorder (SONY TC-255). A preprogrammed magnetic tape caused the LEDs to emit double pulses with a constant period.

For the auditory stimuli, two loud speakers were spaced two meters apart behind the black screen. Each had a sound intensity of 60 dB (SPL) and was connected to the tape recorder through an audio amplifier (PIONEER SA-6600). The same preprogrammed tape caused the speakers to emit double pulses with a constant period.

The double pulses were generated from one direction, left (L) or right (R), or from alternate directions, L or R (see Fig. 1). The duration of each of the two single pulses was 50 ms, and the interpulse interval was 100 ms. The double pulses were generated at intervals of 3, 6, 12, or 24 s in order to examine the decrease in blink rate as a function of interval.

Apparatus for recording. Blink responses were detected with a polygraph (SAN-EI EEG 1A12-12) attached by a pair of electrodes across one eye on the vertical plane. AC amplification with a .3 s time constant was employed, and the recording paper speed was 1.5 cm/s.

Procedure. The subject sat in an electrically shielded room and held a small box with a lever. He was asked to turn the lever immediately to the right if the double pulses were from the same direction, and to the left if they were from alternate directions. A trial consisted of one double pulse. There were four intertrial interval conditions (3, 6, 12, and 24 s) and two modal conditions (auditory and visual), yielding a 4 × 2 paradigm, namely 8 trial blocks of 30 trials each, with interval and mode held constant within each block. The unidirectional and bidirectional presentations were evenly divided (15 times each per block) and the order was randomized across subjects. There was a rest period of approximately one-minute duration after each block of 30 trials.

Quantification of data. An eyeblink was indicated by one sharp, spike-like displacement of the pen, and as such, could easily be distinguished from eye movements. Intertrial intervals were divided into .6 s periods. For example, the intertrial interval of 3 s had five periods. For each block of 30 trials, the average number of blinks for each .6 s period was determined. Lever-turning performance was not analyzed because there were few errors.

Results and Discussion

The results are presented in Fig. 2. For all conditions the blink rate peaked during the second .6 s period after stimuli offset. There was a significant effect of the time course on the blink rate ($F(4,160)$...
K. Fukuda and K. Matsunaga

Interval length had no significant effect on the height of the peaks ($F(3,160)=1.99$). As the time for the next stimulus approached, the blink rate gradually decreased. In both the auditory and visual conditions, there were significant interval-by-time-course interaction effects ($F(12,160)=3.47, p<.01$). The shorter the interval, the faster the blink rate decreased.

There were significant effects of modalities for all of the intervals (for 24 s, $F(1,320)=57.15, p<.01$; for 12 s, $F(1,160)=19.57, p<.01$; for 6 s, $F(1,80)=11.23, p<.01$; and for 3 s, $F(1,40)=7.92, p<.01$). The blink rate in the auditory condition was significantly higher than that in the visual condition for all of the intervals (for 24 s, $t(398)=9.86, p<.001$; for 12 s, $t(198)=4.41, p<.001$; for 6 s, $t(98)=3.08, p<.01$; and for 3 s, $t(48)=2.98, p<.01$). Some subjects said that they were conscious of their blinks only in the visual condition.

There were significant effects of modalities for all of the intervals (for 24 s, $F(1,320)=57.15, p<.01$; for 12 s, $F(1,160)=19.57, p<.01$; for 6 s, $F(1,80)=11.23, p<.01$; and for 3 s, $F(1,40)=7.92, p<.01$). The blink rate in the auditory condition was significantly higher than that in the visual condition for all of the intervals (for 24 s, $t(398)=9.86, p<.001$; for 12 s, $t(198)=4.41, p<.001$; for 6 s, $t(98)=3.08, p<.01$; and for 3 s, $t(48)=2.98, p<.01$). Some subjects said that they were conscious of their blinks only in the visual condition. However, blink rate patterns for the visual and auditory conditions were similar. The visual stimulus inhibited blinking, but it did not change the blink rate pattern.

In this experiment, the post-stimulus blink rate peaks cannot be explained by the blink reflex, for the following reasons: 1) The latency of the blink reflex is shorter than .1 s (Allison, 1932), yet the blink rate in this experiment peaked between .8 s and 1.4 s after the stimulus onset. 2) The LEDs were too dim (4 cd/m$^2$) to generate the blink reflex. 3) The sound was too weak (60 dB) to generate the startle blink reflex.

The following explanations for the peaks were considered: 1) The peaks are caused by the motor responses. Since blinking is caused by the contraction of the orbicularis oculi and the relaxation of Müller’s muscle (McEwen & Goodner, 1969), and since eye movements and blinking are related to muscle activity elsewhere in the body (Meyer, 1953), the motor activity for lever turning could well facilitate the contraction of the orbicularis oculi and the relaxation of Müller’s muscle. 2) The peaks are related to the cognitive system which processes stimuli. Yoshi-mura and Takeda (1978) had subjects who listened to one unit digit 13 times with equal time intervals and mentally calculate these digits. They found some blinks were synchronized with the digits. These findings suggest that the peaks may be related to a cognitive system which processes stimuli.

Experiment 2

In Experiment 1, the blink rate peaked immediately after each stimulus in both the visual and auditory modalities. The peaks, therefore, seemed to be related both to 1) the motor responses and 2) the cognitive responses. The purpose of Experiment 2 was to discover which of the above caused higher peaks.
Method

Subjects. The subjects were five graduate students. Post-experimental interviews indicated that none were aware that their eyeblinks were being studied.

Apparatus and stimuli. The apparatus was the same as in Experiment 1, except the auditory stimulus alone was employed since in Experiment 1 the visual and auditory stimuli caused similar blink rate patterns.

Procedure. A series of auditory stimuli was arranged as $S_1$, $S_2$, and $S_3$. $S_1$ was the warning stimulus; $S_2$, the discrimination stimulus; and $S_3$, the Go-signal for the motor response (see Fig. 3). $S_1$ was presented simultaneously from both the L and R speakers. At 3 s after $S_1$, the $S_2$ double pulse was presented in one direction, either L or R (see Fig. 3(A)), or in alternate directions, either L and R, or R and L (see Fig. 3(B)). At 3 s after $S_2$, $S_3$ was presented simultaneously from both L and R speakers. After about 10 s, the series for the next trial was begun.

In the Experimental Condition, when $S_1$ was presented, the subject had to discriminate whether the double pulse was presented in one direction or in both. When $S_3$ was presented, the subject had to turn the lever only in the case of both directions; he did not have to turn it in the case of one direction. In the second experimental block, the manner of the response to the task was reversed.

The subject was instructed to respond to $S_3$ as fast and as accurately as possible. There was a rest period of approximately one minute after each block of 30 trials. $S_1$ and $S_2$ each had a duration of 600 ms. $S_2$ was composed of two 100 ms single pulses separated by a 100 ms interpulse interval.

In the Controlled Condition, the auditory stimuli were presented, but the subject did not have to respond. The Controlled Condition (C) and the Experimental Condition (E) were each composed of two blocks. The four blocks were arranged in the order CEEC, 60 trials per block, 240 trials altogether. Half of each experimental block required a MR and the other half did not. The presentation order was randomized. The intertrial interval was approximately 10 s.

Quantification of data. The eyeblinks were summed as in Experiment 1, except that the period for counting the number of blinks was reduced to .3 s in order to examine slight changes in the blink rate. The time course began 3 s before $S_1$ onset and ended 3 s after $S_3$ offset. The subjects' lever-turning performance was not analyzed because there were few errors.

![Fig. 3. Temporal relationship of the stimuli. $S_1$ is the warning stimulus; $S_2$, the discrimination stimulus; and $S_3$, the Go-signal for the motor response. (A) $S_2$, double pulse in one direction (illustrated by right-right stimuli sequence); (B) $S_2$, double pulse in both directions (illustrated by left-right stimuli sequence).](image-url)
Results and Discussion

Controlled Condition 1. The results are presented in Fig. 4(A). There were no significant time course effects (for pre-S₁ onset, $F(9,20)<1$; between S₁ onset and S₂ onset, $F(11,24)<1$; between S₂ onset and S₃ onset, $F(10,22)<1$; and for post-S₃ onset, $F(11,24)<1$). The blink rate, then, did not change when no stimulus discrimination was required.

Experimental Condition. The results are presented in Fig. 4(B). There were significant time course effects in each period (for pre-S₁ onset, $F(9,30)<1$; between S₁ onset and S₂ onset, $F(11,96)=6.75$, $p<.01$; between S₂ onset and S₃ onset, $F(10,88)=16.63$, $p<.01$; and for post-S₃ onset, $F(11,96)=1.40$, $p>.1$). The blink rate peaked just after S₁, S₂, and S₃, respectively, but the post-S₃ peak was not significant. The post-S₂ peak was significantly

![Fig. 4. Changes in blink rate in (A) Controlled Condition 1, (B) Experimental Condition, and (C) Controlled Condition 2.](image-url)
higher than the others (S₂ vs. S₃, t(18)=5.66, p<.001; and S₂ vs. S₁, t(18)=3.48, p<.01).

In both the MR and non-MR conditions, there was a significant attenuation in the blink rate between S₁ offset and S₂ onset (F(11,69)=6.75, p<.01). There was no significant difference between conditions (F(1,96)<1). Just before S₃ onset, the blink rate was attenuated in the MR condition, but not in the non-MR condition. There were significant time course effects (F(10,88)=16.63, p<.01) and pre-MR effects (F(1,88)=7.84, p<.01). For the MR condition, pre-S₂ attenuation was not significantly different from pre-S₃ attenuation (F(1,180)<1).

The pre-S₁ mean blink rate in the Experimental Condition was significantly higher than the mean rate for the entirety of Controlled Condition 1 (t(148)=6.81, p<.001). In the Experimental Condition, the blink rate was significantly higher after S₃ offset than before S₁ onset (t(218)=6.81, p<.001). The post-S₃ blink rate was higher in the Experimental Condition than that in Controlled Condition 1 (t(148)=9.47, p<.001).

A peak after each stimulus was observed in the Experimental Condition, but not in Controlled Condition 1. However, the difference between the MR peak and the non-MR peak after S₃ was not significant (t(18)<1). This suggests that the cognitive response elicits much higher blink rate peaks than the motor response. Since the peaks after S₁, S₂, and S₃ had different heights, it might be believed that the cognitive responses were different. In fact, it has been reported that the RTs to S₁ and to S₂ are approximately 150 ms each, and that the RT to S₂ is approximately 400 ms (Hirose, 1981). This could explain why the blink rate peak just after S₃ was lower than that just after S₂; the cognitive load must be higher after S₂.

Controlled Condition 2. The results are presented in Fig. 4(C). The blink rate peaks immediately after stimuli, but does not attenuate before stimuli. There were significant effects of stimuli on the blink rate (for post-S₁, F(9,36)=3.33, p<.01; for post-S₂, F(9,36)=8.00, p<.01; and for post-S₃, F(9,36)=3.50, p<.01). The differences between the heights of the peaks were not significant (S₁ vs. S₂, t(8)=1.51, p>.1; and S₂ vs. S₃, t(8)<1).

In Controlled Condition 2, neither discrimination nor MR tasks were performed. The blink rate did not decrease because the subject did not need to be concerned about the next stimulus. However, the subject might have processed the stimuli, owing to the influence of the Experimental Condition. The blink rate peak was lower in Controlled Condition 2 than in the Experimental Condition.

General Discussion

In Experiments 1 and 2, the following results were obtained: 1) When a stimulus was irrelevant for the subject, the blink rate did not change. 2) When a stimulus was relevant, the blink rate gradually diminished before onset and peaked just after offset. 3) The peak height was greater than the trough depth. 4) Although the visual stimuli caused a greater inhibition of blinking than did the auditory stimuli, the overall blink rate pattern for the two modes was the same. 5) The highest and sharpest peak occurred just after the discrimination stimulus. 6) The motor response did not cause a significant increase in the blink rate. 7) The stimuli continued to elicit peaks even when the subject was no longer asked to respond.

The pre-stimulus decrease in the blink rate coincides with the results of previous studies (Obrist et al., 1969, 1970; Webb & Obrist, 1970). The post-stimulus increase in the blink rate resembles the

---

*This may have partly been due to the fact that the base rate was much closer to its lower limit (zero) than to its upper limit.*
results obtained by Weerts and Lang (1973), but they did not refer to post-stimulus peaks.

When the attention level increases in anticipation of a stimulus, the blink rate decreases. When the attention level abruptly drops after a stimulus, the blink rate peaks. These peaks cannot always be accounted for by a rebound from the inhibition of blinking because 8) in Controlled Condition 2, peaks continued to be elicited for all stimuli, even though there was no pre-stimulus attenuation, 9) for S3, the pre-stimulus attenuation for the MR and the non-MR conditions was significantly different, but the peak height was not, and 10) for the MR condition, the pre-stimulus attenuation for S2 and S3 was not significantly different, but the peak height was.

The results of pupil dilation experiments provide an explanation for (10). During task processing, the pupil dilates proportionally to the amount of a processing load (Beatty, 1982). Now in an experiment employing the same stimuli as the present experiment, the pupil dilated at S1, S2, and S3, but most of all at S2 (Matsunaga, Kumagai, Fukuda, & Funatsu, 1981). Therefore S2 is heavily loaded. The amount of the processing load, then, determines the height of the post-stimulus peaks.

This inference suggests reasonable hypotheses regarding (8) and (9). For (8), the stimuli continue to be loaded and therefore, to elicit post-stimulus peaks. For (9), S3 is equally loaded for the MR and the non-MR conditions. Pupil dilation measurement could verify these hypotheses. A need for further research is indicated.

References


(Received Jan. 19, 1983; accepted Sept. 11, 1983)