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Modeling of Human Spontaneous Eyeblinks

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Abstract—Recent years, researchers have reported that human spontaneous eyeblinks could synchronize in accordance with external visual stimuli. In this paper, to model human eyeblinks, we provided a leaky intergrate-and-fire model with a variable threshold that represents underlying slow oscillation. To test the dynamics of eyeblink likelihood, numerical simulations were performed by changing parameters of the variable threshold. The results demonstrated positively skewed distributions of inter-blink intervals, which were reported in previous behavioral researches. Possible mechanisms of a variety of eyeblink-related phenomenon were discussed.

1. Introduction

Some researchers have reported that viewers likely to blink at implicit breaks in storytelling performances [1] and in video stories [2]. However, the emerging dynamics of eyeblink synchronization among viewers remain as a problem. One manner to approach this problem is to explore the dynamics of eyeblink synchronization by using numerical simulation. Thus, in the present study, we aim to make a differential equation model of human spontaneous eyeblinks.

Human spontaneously blinks 20 – 30 times per minutes [3]. This is approximately 10 times of frequency that is enough to keep humidity of eye surfaces. As spontaneous eyeblinks, human exhibits not only periodical blinking but also quick repeated blinking during a few seconds (i.e., eyeblink bursts [4]). Numerous behavioral researches demonstrate that these blinkings correspond to attentional shifts in cognitive tasks [2].

The recent neurological studies have found that default mode network (DMN) is activated during eyeblinks [5]. The DMN is interpreted to relate to engagement in self-referential mental activities. Hence, some researchers suppose that human would blink in order to withdraw attention back from involving external targets, and then engage in inner processing [5].

These findings suggest that human blinks derive from both endogenetic and exogenetic factors. That is, human eyeblinks are regulated in accordance with external inputs concerning involved tasks, while at the same time, dominated by monitoring the surrounding environment in resting time. To construct a model, we assume a simply formulated situation where a background slow oscillation exists as a regulator of human frequent eyeblinks.

2. Model

We consider a leaky integrate and fire model with a variable threshold. This variable threshold represents a slow oscillation. Let us assume that likelihood of blinking L is governed by the differential equation,

$$\frac{dL}{dt} = -cL + I + \xi, \tag{1}$$

where c is a decay parameter, I is an external input, and ξ is Gaussian noise. The likelihood increases to a threshold $f(t) = a + k \sin \frac{2\pi}{\tau} t$ [7]. In this threshold function, k is an amplitude coefficient and τ is length of period.

When the L reaches to the threshold at each time, it immediately elicits a blink and L is reset to zero. A short amount of time during blinkings, the visual woled is blocked physically by eyelids. Thus, the input $I = 0$ for 0.2 [sec] after each eyeblink elicitation.

In a simple case, if there are no decay and noise, i.e., $c = 0$ and $\xi = 0$, L demonstrates a monotone increasing with accumulating non-negative external inputs I until L reaches the threshold. If ξ is negligible, L increases linearly. However, when $\xi \neq 0$, L would vary in a complex way depending on the variance of ξ. Even if the external input I is constant, inter-blink intervals can show rather complex patterns owing to nonlinearity of threshold oscillation. It is predicted that the extent of inequality of inter-blink intervals depends on the frequency $\omega = \frac{2\pi}{\tau}$ and amplitude coefficient k of the threshold function.

3. Numerical Simulation

3.1. Parameters

In the simulations, parameters were set as follows. The small time for time derivation $dt = 0.01$[sec]. A constant value of threshold $a = 1$. Non-negative external input I obeyed binomial distribution. If we assume the case of a perfect periodical blinks, namely $c = 0$ and $\xi = 0$, L would reach the threshold within averagely 2.5[sec](250 steps). Therefore, the intensity of the external input I is set to $s = 0.04$, taking into account stochastic distribution of I. If the decay parameter c becomes large in proportion to s, L would never reach the threshold. Thus, $c = 0.023$ was relatively selected against to s.

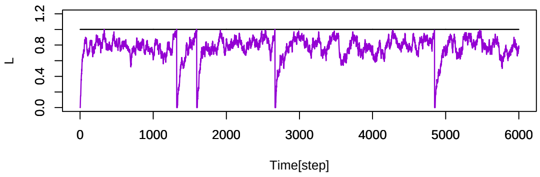
When $\tau = 400$, the frequency is 0.5[Hz]. By taking the limit $\tau \to \infty$, ω approaches 0. In this limit, the threshold takes constant $f(t) = a$. The case that $k = 0.10$ and $k = 0.20$ corresponds to 10.0 % and 20.0 % of the threshold, respectively.

Table 1: Statistical values of simulated and observed [8] inter-blink intervals [sec]

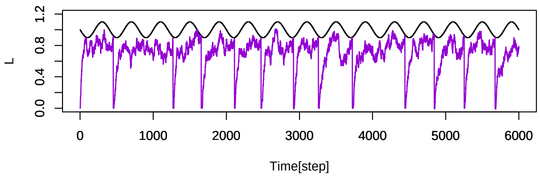
	Min.	Median	Mean	Max.
Simulation	0.590	1.820	3.268	21.420
Observation	–	1.76 ± 2.4	4.3 ± 0.8	–

3.2. Actual human spontaneous eyeblinks

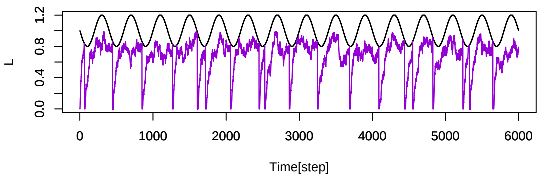
An observational study [8] has reported a variety kinds of statistical values regarding human spontaneous blinking. In the study, blinking of 10 resting subjects without any eye abnormality were observed for 24 minutes . According to Ref. [8], human spontaneous blinking ratio was averagely 17.6 ± 2.4 blinks/minutes and the mean inter-blink intervals (IBI) was 4.3 ± 0.8 [sec]. The distribution is positively skewed, and thus the median of IBIs 2.7 ± 0.5 [sec] was lower than mean IBI. At the same time, logarithm of IBIs probability density and IBIs showed a power law when IBI > 1.025. The exponent α for the power law distribution of scaling, calculated across all subjects, was -1.24. On the other hand, some participants [3] exhibit a bimodal distribution with modes approximately 0.5 [sec] and 5.0 [sec]. The short inter-blink periods reflect eyeblink burst.



(a) $\tau = \infty$



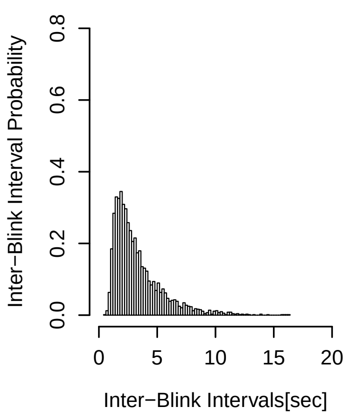
(b) $\tau = 400, \ k = 0.10$



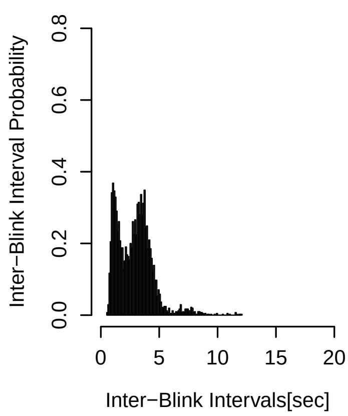
(c) $\tau = 400, \ k = 0.20$

Figure 1: Behaviors variability of L in accordance with threshold parameters τ and k.

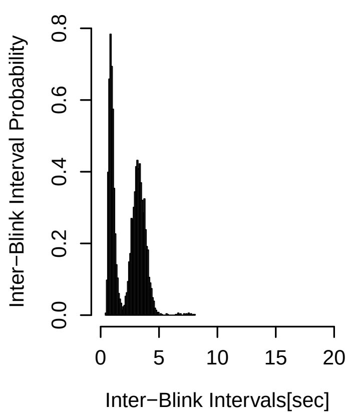
The satisfactory model must represent both periodicity and bursts of blinking.



(a) $\tau = \infty$

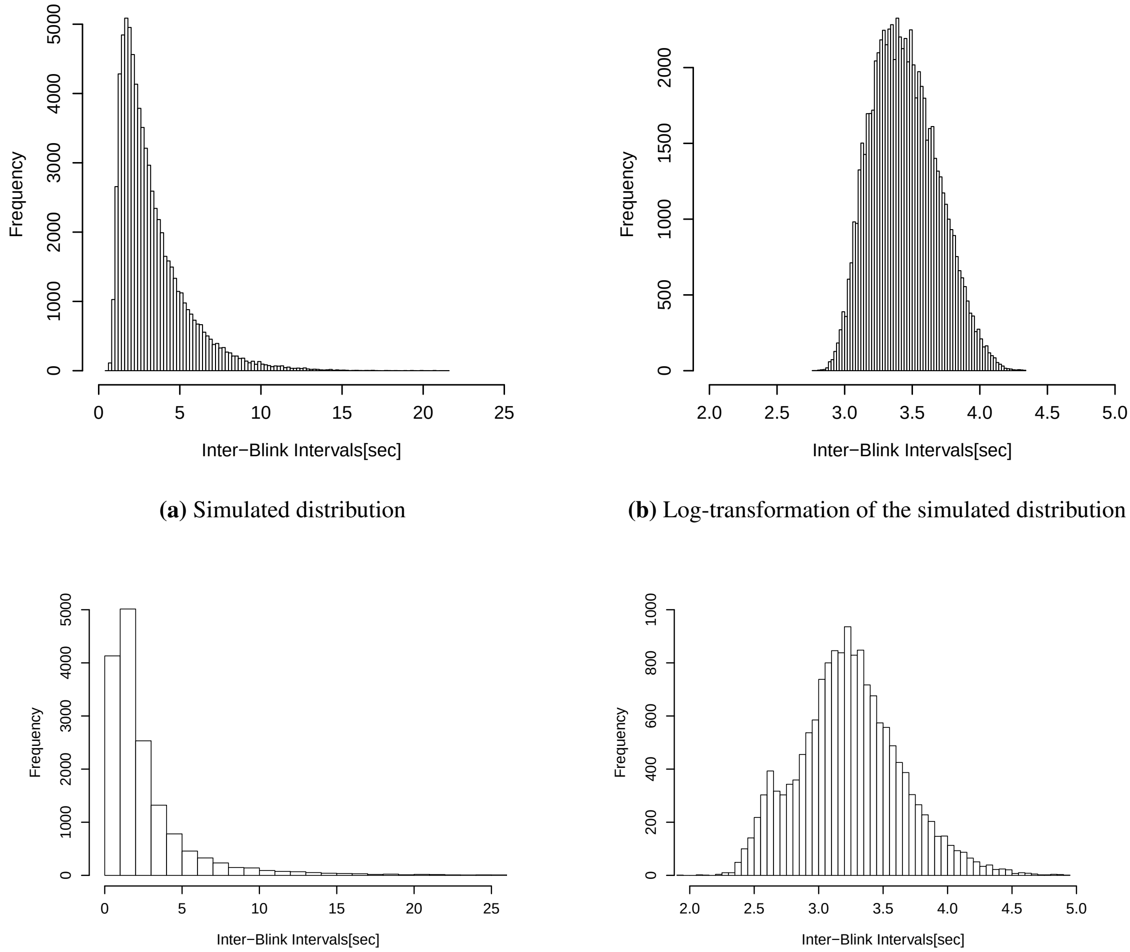


(b) $\tau = 400, \ k = 0.10$



(c) $\tau = 400, \ k = 0.20$

Figure 2: Variation of distributions of inter-blink interval in accordance with τ and k.



(a) Simulated distribution

(b) Log-transformation of the simulated distribution (a)

(c) Observational distribution

(d) Log-transformation of the observational distribution (c)

Figure 3: Simulated distributions and observed distributions [10] of inter-blink intervals.

3.3. Frequency and distribution of inter-blink intervals

First, we conducted a simulation with using a leaky integrate-and-fire model with a constant threshold $f(t) = 1$, where $\tau \to \infty$ thus $\omega = 0$. Figure 1(a) shows the typical behaviors of L in these cases (only first 6,000 steps were plotted). The simulated inter-blink intervals prolonged owing to decay of current L.

Second, we compared the results of simulations in order to test how L behaved in accordance with threshold parameters length of period τ and amplitude k. Figure 1 demonstrated the variation of L's fluctuations under respective conditions. The bimodal distributions were found when the threshold is variable, both for $k = 0.10$ or $k = 0.20$. The outline of the distributions was shown in Figure 2.

We finally exerted a simulation 1000 times under the condition that $\tau \to \infty$, $\sigma^2 = 0.0015$, and $24,000$ steps(240.0[sec]) in order to gain a distribution of stationary blinking. In each performance, the initial values of threshold function were set differently, while all of the initial value of L were set to 0.0. Table 1 shows the statistical values of IBIs obtained from simulations and observations. The distributions of inter-blink intervals were shown in Figure 3. Figure 3(a) is simulated distribution and Figure 3(c) is an actual observational distribution (supplement data in Ref. [10]) obtained from 14 participants who were viewing videotaped storytelling performances for duration of approximately 50 minutes.

4. Discussion

4.1. A model of human spontaneous eyeblink

According to existing studies [3], [4], [11], inter-blink intervals of spontaneous blinks typically show positively skewed distribution. Moreover, the distribution approximate to logarithmic normal distribution when sufficient size of samples was collected [11].

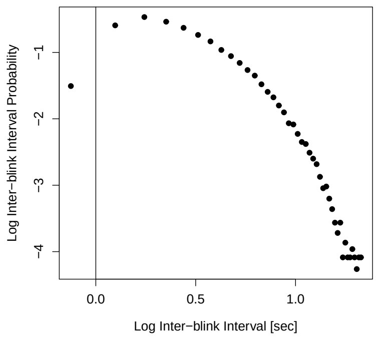


Figure 4: Log inter-blink interval probability of simulated data as a function of the log inter-blink intervals.

As the result of simulations, IBIs demonstrated positively skewed distribution (Fig. 3(a)). The logarithmic transformed data (Fig. 3(b)) was near to normal distribution, and thus inter-blink intervals reproduced by the proposed model would be logarithmic normal distribution.

Logarithm of IBIs probability density and distribution of IBIs showed a power law when IBI > 1.025. The exponent for the power law of scaling was −3.68, which was keener compared to −1.24 calculated using observations.

Regarding IBIs, the ratio of 3.268 per minutes was a little smaller than usual observations of human spontaneous eyeblinks [3]. However, the model in this study reproduced the positively skewed and long-tailed distribution, which characterizes the human spontaneous eyeblinks. Depending on the leak term weighted *c*, the eyeblink likelihood *L* fluctuated near the threshold function. The IBIs distribute in a long-tailed way because the eyeblink likelihood *L* would delay to reach the threshold when the threshold takes a positive amplitude, even if the input *I* intermittedly increase *L*.

4.2. Variation of inter-blink intervals due to variable threshold

The results suggested that length of period and amplitude parameters of the threshold influence on inequality of inter-blink intervals. In particular, the amplitude coefficient *k* of threshold function provided two peaks in the distribution of inter-blink intervals. Eyeblink bursts could be explained by the variable threshold.

The model in the current study could demonstrate both periodicity of blinking and eyeblink bursts by changing parameter of the threshold. Some eyeblink-related phenomena could be explained by this variable threshold. For instance,decrease of eyeblink ratio of patients with Parkinson's disease which is related to decreasing level of a dopamine [9].

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