Spontaneous and voluntary blinking during various long-term activities

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Abstract

We aimed to compare the dry eye associated with spontaneous and voluntary blinking rate among various races and activities. 120 healthy males in three countries were enrolled. The mean age was 36.5 ± 0.8 years. The eyelid movement of all volunteers was recorded by intelligent vision sensor system. Spontaneous and voluntary eye-blinks were measured in races (Taiwan, Japanese and Americans) and daily activities (watching TV, and using computers and smart phones). The subjective and objective changes in dry eye were also evaluated. The frequency of blinks was not remarkable among the races. The maximum blinking interval was shorter in Taiwanese. Spontaneous blinking mildly deceased; by contrast, voluntary blinking increased significantly during the using computers (>4 hours/day) and smart phones (>2 hours/day); this condition manifested with severe dry eye. Ocular dryness was observed after watching TV (> 3 hours/day). This study is the first to discuss the effect of electronic devices by applying a separation line of time on ocular health in the world. The longer time of using electronic devices may result in severe dry eye, and increase blinking rates which may be necessary to refresh the cornea.

Keywords: blink, dry eye, computer, smart phone

1. Introduction

Eye blinking is the fast eyelid movement that closes and opens the palpebral fissure; this movement is elicited by the direct stimulation of the upper and lower motor neuron innervating the orbicularis oculi muscle [1]. A previous study, reported that blink rate is strictly related to dopamine activity in the central nervous system. Blinking is associated with the function of the upper eyelid from several antagonists: levator palpebrae superioris muscle, orbicularis muscles, and palpebral tissues such as upper tarsus, canthal tendons, the levator horns, and Whinall's ligament. Furthermore, the frontalis muscle of the Muller muscle moves when attention is solicited.

Blinking plays an important role in maintaining the ocular surface with tears that spread on the three-layer film [2]. This movement may initiate renewal of the tear film to maintain the physiological integrity of the cornea, clear vision and comfort by protecting, moistening and cleaning the ocular surface [3]. The three types of blinks are spontaneous, reflex, and voluntary. Although the latter depends on the subject's will, the former two are involuntary in nature have different functions [4]. Among various types of blinks, spontaneous blinking is predominant in humans. This type of blinking is an unconscious, transient, or brief closure of both upper eyelids that occur symmetrically and coordinate in the absence of any evident stimulus. Spontaneous blinking may modulate a continuum cycle of evaporation, spreading, and tear drainage. In clinics, patients without spontaneous blinking, especially patients in ICU, may develop superficial punctate keratitis, exposure keratitis, corneal ulcer, and even blindness. During daily activities, blinking is influenced by various diseases and medicine that affect the dopaminergic pathways. In this condition, several factors may influence the frequency of blinking. For example, the rates of blinks increase when individuals glance upwards, experience emotional stress, speak or memorize and undergo corneal stimulation caused by ocular dryness or irritation. However, blinking rates decrease when peoples concentrate or read [5]. In a smoking environment, the frequency of reflex blinking may increase and wash out the carbonic monoxide (CO) to prevent the some toxic substances depositing on the cornea [6].

The balance of tear film remains highly dynamic when the appropriate volume is maintained through tear secretion, spreading, evaporation and drainage. Between blinks, the tear film becomes thinner, and dry spots develop over the cornea and conjunctiva. Blinking initiates the renewal of the tear film to maintain the physiological integrity of the external ocular surface, fine corneal sensitivity, clear visual acuity and comfortable sensation. [7-9]. Deliberate forceful eyelid movement, such as voluntary blinking, may promote secretion from unobstructed glands. The conscious complete blinks likely increase the lipid and aqueous flow and distribution in tears [10]. Prolonged and lasting blinking instead of conscious forceful blinking episodes benefits severe forms of dry eye and improved spontaneous blinking efficiency. However, these two types of blinking are necessary to maintain healthy eyes.

Nowadays, the use of electronic devices has become a huge part of daily activities at home, and at work, as well as in idle hours. The exposure to electronic items, especially video display terminals (VDTs) and various games in computers has been prolonged in office workplace and in leisure time. Recently, various types of smart phones such as i-phones have been popular which has evolved from a rare activity to 6 billion subscribers (87% of the world's population) worldwide, including both adults and children. However, people who regularly use VDTs and smart phones have demonstrated higher incidence of musculoskeletal disorders, eye strain and dry eyes [11,12]. The number of complaints involving ocular fatigue and dry eye among users has increased and these conditions are considered as major sources of this problem [13]. Hence, dry eye is closely related to blinking rate. Therefore, this study aimed to determine and compare the difference among races, occupations, usage of various electronic devices and time spent using such devices.

2. Materials and methods

The study recruited 120 male healthy subjects with various white and blue collar jobs (at least with 10 years of the same professional experience) were recruited in our study. Dry eye was 2.13 times more common among women than compared with men [14]. Therefore, the females were excluded to easily analyze data. Total volunteers who described a history of systemic diseases (e.g. hypertension, diabetes, hyperthyroidisms, and cardiac or respiratory illnesses), some medication use (e.g. anti-histamine drugs and hormone medication), ocular pathology (e.g. amblyopia, strabismus, cataract, glaucoma, keratopathy, and uveitis), ever receiving eyelid surgery, any eyelid abnormality, contact lens wearers, and smokers were excluded because of the effect of these activities likely interfered with tear formation and evaporation [15-20].Only the right eye of each subject was evaluated. All of the volunteers worked from Monday to Friday (5 days in one week and 8 hours in each day), and the blinking rates were measured on Saturday (between 10 to 12 AM) to avoid the confounding effects from overloaded work and the minimal change in tear menisci after the working days. The volunteers were asked not to use any eye drops 1 hour before the research started. All of the subjects were also instructed to sit in the fixed chairs and maintain a stable position of the bodies, heads and eyes during measurement.

According to previous reports, dry eye is significantly more prevalent among humans aged 40 years or older. To eliminate this confounding factor, we selected the subjects aged between 30 and 40 years. Hence, the mean age of the 120 volunteers was about 36.5 ± 0.8 years. This study was performed in accordance with the Declaration of Helsinki, and the ethical approval was obtained.

Written informed consent was also obtained. We aimed to determine the blinking rates of various races (Taiwanese, Japanese and Americans) that have resided in Japan for at least for five years and have engaged in various jobs and activities. The experiments were performed in the laboratory of National Defense Medical Center (Saitama City, Japan) in August 2014. In the room, the temperature and relative humidity were maintained at approximately 20℃-26℃ and 50% to 55%, respectively, to prevent interference [15]. Besides, the condition of illumination was set at 500 lux. The volunteers were instructed to look straight forward during the test.

The refractive errors were measured using the Nidek ARK-510A (NIDEK, Co. Ltd., Japan) auto-refractor directly in each case. The intra-ocular pressure (IOP) was verified with Tonometer KT-800 (Kowa, Co. Ltd., Japan). The mean refractive errors were - 1.50 ± 0.50 diopter (D) (range from - 2.50 to + 1.50 D) in all of the subjects and the cases of astigmatism greater than ± 1.0 D were ruled out. The 120 volunteers exhibited the best-corrected visual acuity (BCVA) of at least 6/6.8, and their IOPs were within the normal range. If the subjects wanted to clearly look at objects in a near distance, the subjects used single focal reading glasses to prevent asthenia and blurred vision.

To measure the frequency of eye-blinks, we used the intelligent vision sensor (IVS) system (Hamamastu, Co. Ltd., Japan). The IVS is a smart sophisticated image sensor that can capture and recognize pictures, and emit control signals in one millisecond (Fig. 1). This high-speed blink analysis system takes images within a short time (1000 photos/second) for easy analysis (Fig. 2). This system is equipped with a high speed frame rate (1600 to 3200 frames/second) which is very common among some researchers recently [21]. Spontaneous and voluntary blinks, the decreased and elevated distances, and the decreased, and elevated times were also measured. During the examination, the subject was instructed to sit before the machine under light-emitting-diode (LED) light exposure. The reflectance utilized an infrared LED to illuminate the ocular surface and the movement of eyelids (Fig. 3). The frequency of eye blinking in the 40-second sessions (spontaneous blinks) was determined by requesting the subjects to blink as rapidly as possibly for 5 seconds (voluntary blinks); the blinks were recorded again. The blinking rate (blinks per minute) was determined from video-graphic records as the average of a 5-minute period. At the same time, the upper eyelid position and movement were plotted every millisecond.

The degree of dry eye was evaluated by Schirmer test. At first, one drop of topical anesthesia (Alcan 0.5%, Alcon) applied to the conjunctival surface of the volunteers' eyes. After 1- minute, the inferior conjunctival sac was placed with the Schirmer Tear Test papers gently. Then the strips were removed and the millimeters (mm) of wetting were recorded. Dry eye is diagnosed on the basis of the Schirmer test score (<5mm/5min). Moreover, the dry eye symptoms questionnaire consisting of six items was administered in a standardized manner by well-trained technicians.

When respondents indicated the presence of a symptom in each time, these volunteers were asked to indicate whether the symptom was experienced rarely, sometimes, often, or all of the time (Table 1) [22]. These symptoms in the answer sheet were associated with dry eye. Considering the answers from the volunteers, we gained data on the associated discomfort and influence of watching TV, and using computers and smart phones.

On the basis of habits, daily work and lifestyle in most workers, spent time engaged in watching TV (separation line: 3-hours/day) and using computers (separation line: 4-hours/day) [23]. For the time spent using smart phones, 50.4% of the adult population used many types of smart phones, and the mean duration of usage is approximate to 1.9 hours per day in Korean [24]. Just now, the percentage of use has increased worldwide. Therefore, the separation line of smart phone usage in our study was 2- hours/day. In addition, all of the subjects used three types of electronic instruments for at least 3 to 5 years. In our experiments, the blinking rate and symptoms of dry eye were investigated in various conditions. The associated problems were further discussed.

Experiment 1: To evaluate the frequency and other parameters of spontaneous blinking rate among the three races.

We aimed to discover the parameters (e.g. blinking rate, decreased distance, elevated distance, decreased time, elevated time and maximum blink interval) of the spontaneous blinking among Taiwanese, Japanese and Americans. The subjects have lived in Japan for at least 5 years. The definition of maximum blink interval (MBI) is the longest time during which human can comfortably keep their eyes open [25]. The subjects were divided into three groups on the basis of different races. Group 1 comprised 40 Taiwanese (mean age: 35.4 ± 1.2 years). Group 2 was composed of 40 Japanese (mean age: 36.8 ± 2.5 years) and Group 3 contained 40 Americans (mean age: 34.9 ± 1.9 years). All of the participants were male. The parameters of each volunteer were checked by applying the IVS system. The rate of incomplete blink reflex was based on the description in a previous study [25], and the number was derived from the sensitive IVS system.

Experiment 2: To evaluate the frequency and other parameters of voluntary blinking among three races

We evaluated some parameters (frequency of blinking, decreased distance, elevated distance, decreased time and elevated time) of voluntary blinking among different races. The demographic characteristics were the same as indicated in experiment 1. We aimed to understand the associated variations among different races.

Experiment 3: To predict the conditions affecting spontaneous blinking rate

We approached the various activities (watching TV, and using computers and smart phones) affecting the spontaneous blinking rate, degree of dry eye, and subjective symptoms of the volunteers. The prolonged time spent in watching TV was defined as greater than 3- hours/day (N = 50). The prolonged time in using a computer was greater than 4-hours/day (N = 70). The excessive habit of utilizing a smart phone was longer than 2-hours/day (N = 75). The results of Schimer test and subjective symptoms of dry eye were also verified among these electronic users.

Experiment 4: To assess the conditions affecting voluntary blinking rate

We attempted to analyze the effect of various activities (watching TV, and using computers and smart phones) on the voluntary blinking rate, degree of dry eye and subjective symptoms of the subjects. The spent time greater than the separate line in watching TV, and using computers and smart phones was the same as indicated in experiment 3. Furthermore, we also compared the results of Schimer test and subjective symptoms of the dry eye of the subjects.

Experiment 5: To evaluate the different jobs influencing blinking rate and dry eye

We aimed to realize whether different jobs could influence the blinking rate and dry eye. The jobs of the 120 subjects were divided into two types: white collars (official worker; N=65) and blue collars (laborers; N=55) which the subjects have been engaged in the same work for at least five years. White collar employees (most of these employees are official workers) needed longer times in front of computers, VDTs, and smart phones for business-related purposes than blue collar workers. In other words, the white collar workers spent relatively longer time to work with electronic instruments. In this experiment, spontaneous and voluntary blinking was analyzed and compared between official workers and common labors. Besides, the degrees of dry eye were appraised together.

Experiment 6: To estimate the impaction on watching TV during different times

We conferred the results from the different times spent in watching TV. The spent time in watching TV was relatively short after work because the subjects had regular work in the morning (at least 8 hours per day), Therefore, we divided the 120 subjects into two groups on the base of leisure time. In Group 1, the time of watching TV of 70 persons was less than 3 hours/day after work. In Group 2, 50 volunteers spent longer than 3 hours in watching television programs off duty every day. We compared the frequency of the two groups. Besides, schemer test was also used to evaluate the condition of dry eye.

Experiment 7: To investigate the influence of using computers during different times

We inquired to the results related to the time spent using computers. The workers, especially the official clerks, used computers during working hours (some special cases needed 9 to 10 hours/day in front of computers). In addition, most of the subjects were interested in playing the computer games and utilizing the Internet after business hours. The 120 subjects were divided into two groups on the basis of time usage. In Group 1, 50 subjects spent less than 4 hours of continuous computer uses every day. In Group 2, 70 volunteers spent more than 4 hours/day of computer use during and after work. In this experiment, the blinking rates and degrees of dry eye were compared between the two different times.

Experiment 8: To determine the effects on the smart phone users during different times

With the increase in the number of individuals using smart phones, the usage of smart phones in the current study and the associated issues had been valued. In this experiment, all subjects were divided into two groups. In Group 1, 45 men used smart phones (< 3 hours/day) for leisure activity and 75 subjects yielded them up to use smart phones (> 3 hours/day) during free time after work in Group 2. We compare the rate of blinking and the level of dry eye in two groups.

All data were presented as mean ± standard deviation (SD). The statistical analyses were performed using IBM SPSS statistics version 21 (Armonk, NY: IMB Corp). One way analysis of variance (ANOVA) and pair-t test were conducted to compare the differences in all of the experiments. A level of *P* value of less than 0.05 was considered to indicate a statistically significant difference.

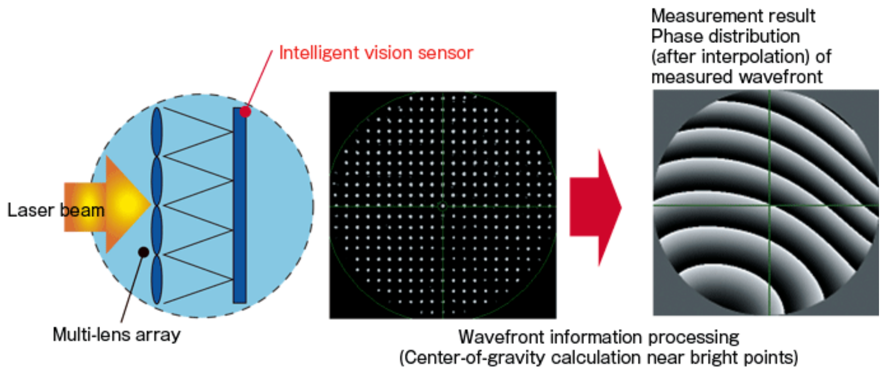

Figure 1. The intelligent vision sensor system has the characters of high-speed and high-precision. It can detect and measure the movement of the target by special laser.

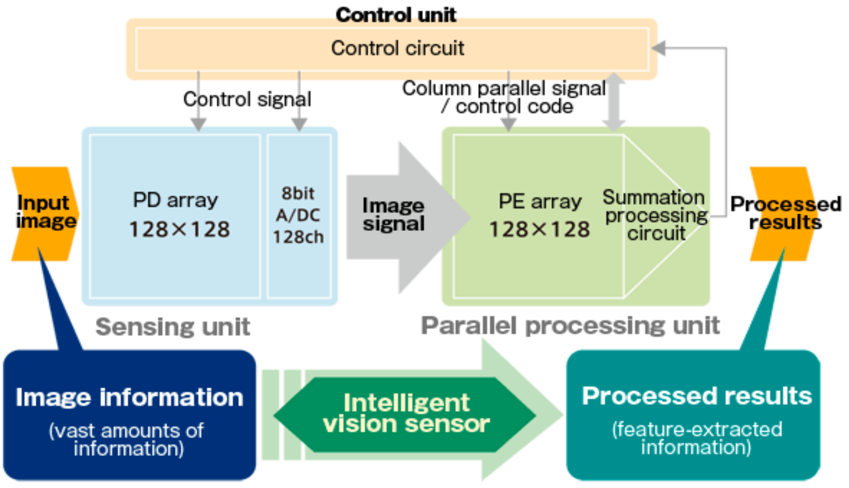

Figure 2. Intelligent vision sensor is a smart, sophisticated image processing sensor that can capture and recognize images, and emit control signals in a very short time (one millisecond).

Figure 3. Intelligent vision sensor with a camera that performs high-speed parallel image processing by using the number of parallel processing elements equal to the number of pixels. The camera processing mode can be changed by the program. For example, data acquired with multiple cameras (1 to 4 cameras) can be synchronously fed to the parallel processing circuit that performs real-time processing to output only the calculated results or control signals. This allows real-time control of images containing a vast amount of information with low latency (lag).

3. Results

Experiment 1:

We found that the mean spontaneous blink rate (18.8±1.5 /min) among Taiwanese volunteers was slightly shorter than the mean spontaneous blink rates of the Japanese (20.1±3.8 /min) and the Americans (21.1±2.5 /min). However, the difference was not significant ($P > 0.05$). The MBI was relatively shorter (9.1± 2.4 sec) among Taiwanese than that of the Japanese and Americans ($P > 0.05$). However, the other parameters did not differ from among the three groups (Table 2). Therefore, the comfortable eye-open time of the Taiwanese volunteers was shorter because of the persistence of ocular fatigue and dry eye. On the basis of the IVS system, we also found that the percent of incomplete blink in relation to total complete blinks was 13 % (Taiwanese) which was greater than 8% (Japanese) and 7% (Americans). Therefore, some individuals suffer from dry eye possibly caused by incomplete blinking which is attributed to the development of meibomian gland dysfunction and further cause rapid evaporation as a result of the in sufficient lipids [25, 26].

Experiment 2:

The mean voluntary blinking rate (12.4 ± 2.7 /min) among Taiwanese volunteers significantly decreased in Japanese (20.5 ± 3.3 /min) and Americans (22.3 ± 2.4/min) ($P < 0.05$). Besides, the time of MBI was also shorter among Taiwanese (8.5 ± 1.4 sec) than Japanese (15.3±1.5 sec) and Americans (15.5 ±3.2 sec) ($P < 0.05$) (Table 3). Hence, most of the Taiwanese may suffer from ocular fatigue because of dry eye caused by the lack of tear formation.

Experiment 3 and 4:

We compared spontaneous and voluntary blinking, and the degrees of dry eye of 120 subjects in various activities. The spontaneous blinks as a consequence of using computers and smart phones were less than those as consequence of watching TV ($P < 0.05$). Furthermore, the voluntary blinking of the volunteers using computers and smart phones was longer than the ones in watching TV ($P < 0.05$). Furthermore, the voluntary blinking of those the longer daily activities of the subjects including using computer, and smart phone may result in dry eye of subjective and objective symptoms. We defined that the severe dry eye from the questionnaire (in our table 1) is the symptoms≧5 criteria [22]. We found that the longer time during the above two daily activities may bring about the apparent discomfort of sever severe dry eye. The findings were presented that the associated symptoms about dry eye were incident to the habits of longer-term use of computer and smart phone. Therefore, in our studies, the incidences of severe dry eye in is approximate to 50% (60/120; computer users) and 83.3% (100/120; smart phone users), respectively (Table 4 and 5).

Experiment 5:

Blinks are very important in some delicate and sensitive works and tasks. Dry eye may result in poor vision which can affect work performance. We analyzed the influence on the official clerks who performed data processing by using computers and VDTs. We discovered that voluntary blinking rates and the level of dry eye were among white collar workers than among blue collar laborers. These results indicated that the official clerks who spent prolonged time using computers, VTDs, and smart phones may affect the rate blinks ($P < 0.05$) (Table 6).

Experiment 6:

We divided the 120 subjects into two groups according to the time in watching TV daily (< 3 hours and > 3 hours). To our surprised, the influence of the time spent watching TV programs on human blinks was not apparent ($P > 0.05$). By contrast, the prolonged time (> 3 hours) in watching TV may reduce the tear production and therefore, induce the symptoms of dry eye ($P < 0.05$) (Table 7).

Experiment 7:

The volunteers were divided into two groups on the basis of the different times spent in using computers daily (< 4 hours and > 4 hours). We found that the effect impaction from the longer time of activities (total using time > 4 hours / per day) before the computers (e.g. playing game, using internet and sending e-mail) may result in the increase of voluntary blinking and reduction in tear film formation significantly ($P < 0.05$) (table 8).

Experiment 8:

The 120 subjects were divided into two groups on the basis of the time spent in utilizing smart phone every day (< 2 hours and > 2 hours). We found that impaction from the longer time (total using time > 2 hours/day) in using the smart phones may increase the voluntary blinking rates and dry eye occurrence , which may bother the users ($P < 0.05$) (Table 9). We suggested that individuals using smart phones require a large amount of tears to protect the external surface of eye and enhance their vison.

Table 1. Dry eye questionnaire

1. Do your eyes ever feel dry ？
2. Do you ever feel a gritty or sandy sensation in your eyes ？
3. Do your eyes ever have a burning sensation？
4. Are your eyes ever red？
5. Do you notice much crusting on your lashes？
6. Do your ever get struck shunt in the morning？

***** Allowable response : rarely, sometime, often, or all of the time

Table 2. Spontaneous blinks of three different races

Races / Parameters	Taiwanese	Japanese	Americans
Frequency	18.8 ± 1.5	20.1 ± 3.8	21.2 ± 2.5
Decreased distance	6.0 ± 1.2	5.9 ± 1.8	6.8 ± 1.4
Elevated distance	5.8 ± 2.4	5.6 ± 2.9	6.08 ± 2.7
Decreased time	87.5 ± 5.7	90.2 ± 7.9	92.8 ± 6.9
Elevated time	179.5 ± 6.8	180.5 ± 7.5	189.2 ± 8.7
MBI	9.1± 2.4	16.3 ± 1.5*	15.9 ± 3.2*

Frequency： /min, Distance: mm, Time: msec, MBI: sec

*P < 0.05, compared with the parameters of Taiwanese (which showed apparently difference)

Table 3. Voluntary blinks of three different races

Races / Parameters	Taiwanese	Japanese	Americans
Frequency	12.4 ± 2.7*	20.5 ± 3.3	22.3 ± 2.4
Decreased distance	6.5 ± 1.2	7.1 ± 1.8	7.2 ± 2.8
Elevated distance	6.2 ± 0.4	6.9 ± 2.2	6.4 ± 2.9
Decreased time	83.8 ± 2.9	84.2 ± 2.4	8.6 ± 2.8
Elevated time	168.2 ± 3.9	172.3 ± 4.4	172.8 ± 4.8
MBI	8.5± 1.4	15.3 ± 3.5*	15.1 ± 2.2*

Frequency： /min, Distance: mm, Time: msec, MBI: sec

*P < 0.05, compared with the parameters of Taiwanese (which showed apparently difference)

Table 4. The rate of spontaneous blinking in different activities

Parameters / Types	Frequency	Schimer test	Numbers of symptoms		
			None	≧ 3	≧5
Watching TV	17.9 ± 2.4	10.5 ± 2.5	100	20	0
Using computer	12.9 ± 3.2	2.5 ± 1.0 *	20	60	40
Using smartphone	10.8 ± 2.5	1.5 ± 1.0*	0	10	100

Watching TV (N= 50; the time > 3 hours/day), using computer (N= 70; the time > 4 hours/day), using smartphone (N= 75; the time > 2 hours/day).

Frequency： /min, Schimer test : mm.

* $P < 0.05$, indicated significant difference (compared with watching TV).

Table 5. Voluntary blinking in various activities

Parameters / Types	Frequency	Schimer test	Numbers of symptoms		
			None	≧ 3	≧5
Watching TV	15.9 ± 2.8	10.5 ± 2.5	90	20	20
Using computer	23.9 ± 2.2*	5.5 ± 1.5 *	20	40	60
Using smartphone	27.8 ± 2.7*	4.4 ± 2.5*	0	20	100

Watching TV (N= 50; the time > 3 hours/day), using computer (N= 70; the time > 4 hours/day), using smartphone (N= 75; the time > 2 hours/day).

Frequency： /min, Schimer test : mm

* $P < 0.05$, indicated significant difference (compared with watching TV).

Table 6. The effects of blinking and dry eye evaluation in different workers

	Blue collars (N=55)	White collars (N=65)
Frequency		
Spontaneous	20.9 ± 2.4	12.7 ± 2.9*
Voluntary	12.8 ± 2.5	20.8 ± 1.2*
Schimer test	9.5 ± 0.5	1.0 ± 0.5*

Frequency： /min, Schimer test : mm

* $P < 0.05$, compared with the data of blue collars significantly.

Table 7. The effects of the amount of watching TVs on blinking rate and dry eye evaluation

	<3 hours/day (N=80)	> 3hours/day (N=40)
Frequency		
Spontaneous	19.2± 1.5	22.1± 3.4
Voluntary	17.5± 2.8	21.7± 2.7
Schimer test	10.4 ± 2.5	2.5± 1.5*

Frequency： /min, Schimer test : mm

* *P* values of less than 0.05 were considered statistically significant (compared with the using time less than 3 hours/day).

Table 8. The effects of the amount of using computers on blinking rate and dry eye evaluation

	< 4 hours (N=65)	>4 hours (N=55)
Frequency		
Spontaneous	18.5 ± 2.5	26.2 ± 3.5*
Voluntary	16.1 ± 3.8	26.2± 2.5*
Schimer test	5.4 ± 2.5	1.0± 1.0*

Frequency： /min, Schimer test : mm

* $P < 0.05$, presented the results significantly. (compared with the using time less than 4 hours/day).

Table 9. The effects of the amount of using smartphones on blinking rate and dry eye evaluation

	< 2 hours (N=70)	> 2 hours (N=50)
Frequency		
Spontaneous	17.8± 1.5	26.3± 2.5*
Voluntary	16.5± 2.8	27.2± 2.4*
Schimer test	10.4 ± 2.5	2.5± 1.5*

Frequency： /min, Schimer test : mm

* $P < 0.05$, showed statistically significant difference (compared with the using time less than 2 hours/day).

4. Discussion

Tear dynamics is determined by three factors: production, evaporation, and drainage. The kinetics analysis timed with the onset of eyelid blinking is benefit for the human eyes. Blinking is closely related to tear dynamic between blinking and tear dynamics is very close [27]. The blink rates and completeness of blinking can significantly affect tear film dynamics and ocular surface health. During blinking, the active lacrimal pump process is mediated by a gradient of pressure changes in the lacrimal canaliculi and sac; the changes in pressure are induced by orbicularis contraction and relaxation. The blink rate is essential for normal drainage because the tear flows into the canaliculi during the up phase of the blinks [28]. Tear film is necessary to maintain ocular integrity, improve vision, create comfortable sensation and provide effective defense. If frequency of blinks deceased, dry eye with unstable film could happen and further result in aqueous or lipid tear deficiency [29]. In general, spontaneous blinking rate exhibits a moderate increase, rather than a decrease, with age. However, voluntary blinks do not deteriorate with age [30, 31]. Thus, a clear and healthy cornea must be maintained by keeping the moisture of the anterior surface of the epithelium; this condition requires the physiological types of blinking.

On average, the blinking rate is approximately 12 to 22 /minute in different studies [33, 34]. The disparities between the previous studies are attributed to the dependence of the blink rate on varying experimental conditions for measurement. For example, individuals have considerable variation in eyelid dynamics, and the factors associated with different types of blink in the same subject are consistent [35]. Doane found con0that there were considerable variations in eyelid dynamics between individuals [8]. Changes in human blinking are generally age-related. Previous studies revealed different results. For example, the spontaneous eye rate is 13.8 ± 9.7 blink/min (median age 36 years) among British people [18]. Sun et al. also found that spontaneous blink rate was 23.8 ± 9.7 /min (mean age: 40 to 49 years) in American [17]. In addition, the average spontaneous blinking frequency was 18.4 ± 3.4 per min in Frenchman [18].

Different races exhibit different frequencies because of several factors influencing the results; however the exact explanations remained unknown. In general, Asian eyes have a shallow orbit, small vertical orbital dimensions and differences in the upper eyelid anatomy compared to Caucasians [36, 37]. They also have narrow palpebral fissures. Besides, Yaginuma et al. suggested that a wilder palpebral fissure, and hence greater exposed ocular surface area, as well as a lower blink rate [19]. Furthermore, Albietz et al. demonstrated that the blinking in each race is related to the eyelid surface anomalies, and anatomical differences in the orbit [38]. Dry eye is more prevalent in Asian population, especially in Taiwan, than in Caucasians, and their report was the similar as ours that the Taiwanese yielded significantly shorter MBI [39]. This result is indicated that the Taiwanese are susceptible to ocular fatigue and dry eye sensation. Besides, the various rate of vaporization of each individual may be another factor [40].

Studies on eyelid dynamics have identified three types of eye blinks including spontaneous, voluntary and reflex [41]. Among these types, spontaneous blinking is the most discussed and important. Virtually absent at birth, spontaneous blinking increasing steadily until adolescence and reaches a plateau that is maintained through adult life [32]. However, the decline in blink amplitude and peak velocity with age is less distinct in voluntary blinks than in spontaneous blinks. Spontaneous blinking is a normal function of vertebrates with eyelids which is thought to be under the control of central dopaminergic mechanism [1, 42]. This mechanism involves the simultaneous closure of upper and lower eyelids in both eyes that are conscious, bilateral, symmetrical and rhythmic. Movement should be partial, hindered (e.g. after ptosis surgery or facial palsy), incomplete (most of the time) or complete (more rarely). Its mechanism is due to the contraction of the pre-tarsal orbicularis muscle. Conversely, voluntary blinking is complete and caused by contraction of the pre-septal and pre-tarsal orbicularis muscles. During voluntary blinking, the significant increase of vertical amplitude, horizontal amplitude, and closure speed occurred, when compared to the spontaneous blinking. Some condition which may activate the pre-tarsal portion of the orbicularis muscle and the recruitment of fast (high-frequency) motor neurons may influence the frequency of voluntary blinking. In addition, reflex blinking could happen under unique circumstance, such as in smoking environment [41].

According to the criteria described by Japanese scholars, the maximal decreasing velocity of incomplete blinking in the upper eyelid is 2.5 times greater than the maximal increasing velocity (mm/sec) [42].We found that incomplete blinking rates of the Taiwanese, Japanese and Americans are 13%, 8%, 7%, respectively. Ineffective blinking may bring about dry eye among the Taiwanese under any condition which is the highest percent among the three races. Under the high-speed camera of IVS system, we could track that the incomplete blinks faster than the transitional methods used in previous studies. A blink is described as incomplete when the upper eyelids do not touch the lower eyelid, even with only a very minor gap between the eyelids. This phenomenon could be easily detected by gross eye and traditional method; however, the IVS system in our experiments could find out the subtle sings effectively. Indeed, the incomplete blinks play an important role in the relationship between meibomian gland dysfunction [43]. Lipid constitutes the outer layer of the tear, and a defect in this layer may result in rapid evaporation and dry eye formation. The higher percent of incomplete blinking could explain the high rate of dry eye in Taiwanese people. Incomplete blinking may also cause an area of the inferior cornea and the remainder of the corneal surface to easily wet, which may induce the deleterious effects later. For example, exposure keratopathy, was found in some cases and easily developed into more severe forms of keratopathy and even corneal ulcer. The contact between eyelid and cornea aids in replacing mucin on a regular basis by actually rubbing fresh mucin onto the corneal surface [43-45].

Blinking is needed to aid the flowing of tear. The tear fluid presents a typical complex multi-layered thin fluid with intrinsic dynamicity which is a 7-µm-thickness biological fluid on the external ocular surface. Frequent blinking, once every 4-5 seconds, puts the tear film in a constant flux and requires it to repeatedly on cornea after each blink within a few milliseconds to adequately perform its physiological and protective function. Given that the tear layer is very thin (typical 6µm to 10 µm), evaporation and lipid contamination of the tear fluid’s mucin component quickly destroys its continuity. This behavior results in breaks or dry spots on scattered locations on the corneal surface usually within 15 to 30 seconds after a blink. The blinking action of the eyelids, which usually occurs before the formation of dry spots, is required to reform the tear film layer. Ophthalmologists believe that the blink interval must be shorter than the film break-up time. Therefore, the treatment regimens of various corneal disorders were focused on the spreading of the tear fluid by blinking action of the eyelids [46].

Inner canthal orbilularis drives the spontaneous blinking eyelids and it may combine with series of proper eyelid tension; contraction of orbicularis results in the normal physiologically blink mechanism about the spontaneous and voluntary [15, 16]. It is richly innervated by a branching network of twigs based on the buccal branch of the facial nerve. Hence, evaluating the palpebral dynamics is useful and important in studying the topics of blepharo-spasms, facial palsy, and dry eye. Tear fluid spreads into a thin film when blinking, which is important for ocular health. Moreover, blinking facilitates meibum excretion from the meibomian glands and generates upward excursion of the upper eyelid, which may help the spread of aqueous and lipid over the corneal surface [47]. After blinking, the lipid film rapidly in horizontal propagating waves from the lower to the upper cornea in healthy subjects. Within a mean period of 0.36 ± 0.22 seconds, the tear reached a stable image and remained so thereafter. During this time, the lipid was distributed throughout the entire central part of corneal surface with a mean estimated thickness of 74.5 ± 6.9 nm. Therefore, the tear may be preserved for a long time for eye care [47, 48].

The upper eyelid rapidly moves as it crosses the visual axis. The velocity is usually 15-25 cm/sec, but the velocity of 40 cm/sec was noted on a few instances. The blinking rate is determined by many factors. Relationship between age and complete blinking combined with decreased tearing was mainly found [14]. Moreover, blinking rate was shown to be correlated with some medical condition such as fatigue, lapses of attention, mental disorders, dystonia, Gilles de la Tourette disease, Huntington’s disease, blepharo-spasm, hemifacial spasm, ptosis, facial nerve palsy, progressive supra-nuclear palsy, strokes, topical anesthesia, wind, and illumination [49-53]. Further studies revealed that several factors influence spontaneous frequency: it increases when glancing upwards, emotional stress (anxiety, depression, psychosis), schizophrenia, when glancing upwards, speaking or memorizing, sleep deprivation or through corneal stimulation caused by dryness or irritation of eyes [54-57]. On the contrary, factors that decrease blinking rate include concentrating, reading, Graves’s orbitopathy, attention deficit/hyperactivity disorders, alcohol abuse, recreational cocaine use, mental retard, Parkinson’s disease, and dry eye [58-60]. For example, Zemetkin et al. reported that some tasks involving memory increase blink rate, whereas those that required visual fixation (such as reading and using smart phones) reduce blinking rate [32]. Tsubota et al. also demonstrated that the blinking rate may decrease during computer work and book reading [27]. Recently, advance research showed that human blinking is also affected by various race, moisture, circumstances, genetics, nutrition, immune status, and several diseases [61-63]. In some studies, blink rating was considered as a putative marker of central dopamine activity and may serve as a useful clinical indicator of symptomatic status such as stress and excitement. It is interesting that the frequencies of blinking were 67/min for George Bush and 75/min for Michael Dukakis during their television debate for the 1988 US presidential campaign, suggesting that both candidates were under stress [47].

The cases of contact lens users and the peoples undergoing laser in situ keratomileusis (LASIK) are increasing because of the advancement of refractive surgery and optic technology. Therefore, associated problems were highly valued. Berry et al. revealed that contact lens wearers and LASIK patients (especially after one month) may lower blinking rates because the decreased tear clearance changes the morphology of the ocular surface rate [64,65]. Furthermore, various and different types of contact users all may reduce tear and mucins clearance, enhance corneal wetting, resulting in eye comfort and even changing life quality [66-68]. Give that contact lenses may interfere with blinking rate, users could not clear the debris depositing on the contact lens and external eye surface. Hence, Tsubota et al. reported that higher risks of keratopathy and corneal surface damage may be easily found in contact lens wearers because of dry eye. For example, the prevalence of lid wiper epitheliopathy ranges from 76% to 80% among contact lens users with dry eye syndrome [62]. Furthermore, approximately 73% of contact lens wearers show some degree of parallel conjunctival folds; likewise, at least 40 % of contact lens wearers own the sign [69].

Ocular complaints about discomfort and dry eye experienced by VDTs users became the increasingly common and hot topics in clinics. In our research, symptoms of dry eye and more frequent voluntary blinking was apparent in long-time computer users for the purpose of increasing the secretion and formation of tear. Recently, dry eye has been considered a major source of ocular fatigue from the view of most ophthalmologists. For example, Toda et al. demonstrated that ocular fatigue is the major symptom of dry eye. They found that the 51.4% of patients who complained of eye fatigue were diagnosed with dry eye [70]. Furthermore, 70 % of dry eye patients complained of ocular fatigue that prevents them from keeping their eyes open, reading books, or watching TV for a long time [71].

Some anecdotal evidence suggested that asthenopia (eye strain) among VDT users may be caused by poor screen legibility and stability. Vertical head posture by VDT users may lead to the greatest head posture, neck pain and ocular discomfort [72]. The eyeball and associated head position may regulate and influence the blinking intervals. Besides, the mean blink rates were approximately 1.6 to 2.3 times higher in subjects looking straight and up than down (increase in the exposed ocular surface significantly increases the blink rate). In other words, blinking rate may decrease when the eyes are in straight and upward position rather than downward position. Some researchers found that horizontally oriented eyes have greater ocular surface exposure, and consequently, greater tear and fluid evaporation. Short et al. proposed that when the eye looks toward computers, therefore, the upward-looking situation may decrease blink rate [73]. However, Murube et al. had different findings stating that when looking at a distance (approximate 5 m), the mean of blink/min of subjects was 17.0 ± 3.4. When looking near (30 cm in distance) combined with the inclination of the head in relation to horizontal axes (33 degrees) and inclination of the eyes in relation to the axial plane of the head (20 degrees), the rate of blinking was 14.3 ± 2.7/ min. When looking near with the eyes in a horizontal position (at the desktop computer VDT: 30 cm in front of their eyes), the mean blink was 11.4 ± 1.8/ min [4, 45].

In this study, we found that peoples who use computers and bend their head to play smart phones showed decreasing spontaneous blinking; however, voluntary blinking is increase when the patients feel the dry and discomfort sensation. Nakamori et al. found that the mean blink in dry eye patients, which is 34.1 ± 2.4 per minute, was greater than that of the control subjects (20.1 ± 2.4 per minute) [2]. Furthermore, McMonnies reported that using a computer was found to even lower the blink rate to 4 blinks / min [43]. So, why the does the same movement of eye blinks has the different results in various reports？The fluctuation needs detailed evaluation if it was caused by dissimilarly designed measurement, various experimental conditions or different instruments. We suggest that the results of difference may be caused by the resolution of dissimilar instruments used in various researches. In the past, only the total tear volume changes in the palpebral fissure could be quantified by scintigraphy and dye methods. Besides, the typical eyelid closure occurs in about 80 msec. Even at 64 frames /sec (four times normal silent film rate), the entire downward motion of the upper eyelid is represented by at most four frames. This is not enough for detailed temporal resolution of eyelid motion [5]. In recent years, the video meniscometry, interferometry, real time optical coherence, electrooculography (EOG), electroencephalography (EMG), electroencephalography(EEG), infrared light beam, magnetic coils, optoelectronic motion detector, dynamic device consisting of a CCD camera, and LipiView interferometer have been used to capture more exact blinking frequencies [74-78]. In our experiments, the intelligent vision sensor system with the special characters about high-speed and high-precision is the best tool in evaluating various diseases actually. Therefore, all results of our studies should supply the useful references to others. In addition, most of the researchers believed that the blinking rate in dry eye patients may increase, and at least the results of eye blinks are similar to health people.

Namakori et al. used the different method of mean blink interval (MBI) to evaluate the people with dry eye. They also found that volunteers who used the VDTs for 60 minute and the mean MBI may drop from 10,9 ± 1.8 seconds to 6.4 ± 0.71 seconds because of ocular fatigue and dry eye [2]. In other words, these subjects needed another blinking to refresh the corneal surface with the tear film in a short time. Therefore, we strongly suggested that using computers and smart phones sometimes and even overtime is an important risk factor in dry eye and other associated problems. In our study, we found that MBI in spontaneous and voluntary blinking was shorter in Taiwanese because of ocular strain. It means that the Taiwanese people are prone to dry eye development. Besides, the decreased distance, elevated distance, decreased time and elevated time of upper lids in blinking were not significantly apparent among the three races in our research. It needs further evaluation in the future.

A large series of studies about the use of TVs, computers, and smart phones in elementary schoolchildren aged 9 - 11 years was conducted. Among the participants, all of the children watched TV programs, and 52.1 % used smart phones. According to Moon's survey, the daily use of computer and TV use alone was not associated with increased dry eye, but subjects who used both smart phone and computer reported more ocular symptoms, including visual fatigue, dry eye and headache. Nevertheless, we found in our study that watching TV daily (> total 3 hours in one day) do not decrease blinking rates, but may decrease tear formation. In our opinion, this may be caused by the farther distance when they have from the TV while watching. The spare accommodative force may be preserved and ocular fatigue was not apparent. Therefore, peoples watching TV do not need to blink more. The use of computers, especially smart phones, may easily result in severe symptoms and signs of dry eye; this result was similar to our findings, which were also consistent with those of Moon [79].

Dry eye disease is defined as a multifactorial disease with tear deficiency and several ocular discomforts such as visual disturbance, tear film instability, and potential damage to the ocular surface. The prevalence is estimated to be 7.4% to 33%, depending on the diagnostic criteria used and population surveyed [80]. In our study, we used the very popular method used by most ophthalmologists worldwide to evaluate the condition of dry eye. On one hand, the data of Schimer's test was not strongly consistent with the subjects with dry eye, and the method was not considered as gold standard for diagnosis. On the other hand, Schimer's test could be easily and commonly used for reference and objective analysis of dry eye in ophthalmic clinics. However, a lot of authors in various studies strongly suggested that the blinking rate is indicative of dry eye. For example, Nakamori et al. demonstrated that individuals were diagnosed with dry eye disease, based on blinking rates [2]. In clinics, dry eye has been shown to be a major source of ocular fatigue that is strongly associated with VDTs and smart phones [81]. Moreover, the use of VDTs, computers and smart phones is associated with the change of blink rate, increased palpebral fissure width, and tear evaporation, each of which can contribute to dry eye [31,77]. Several literatures mentioned the relationship between dry eye and the frequency of blinking rate; however, the change of blinking rates while watching or patient with dry eye also became controversial. For example, the near vision accommodation in different views of VDTs induces the lower frequency of blinking in dry eye subjects. Murube et al. revealed that maximum blinking rate (average 17 /min) was observed when subjects focused from a distance with their eyes in the primary position. However, minimum blinking rate (average 14 /min) was observed when subjects focus horizontally. In another research, the blink rates decrease in the subjects focusing on VTDs, at a distance and near at a downward angle [81]. In addition, lower blinking frequency in horizontal plesiopsis during VDT induced greater evaporation and resulted in dry eye. Other reports also noted a strong association between computer vision syndrome and dry eye, with longer periods of computer work being associated with higher prevalence of dry eye [76].

Dry eye and other diseases associated with the use of VDTs, computers and smart phones are highly respected. Ponder and Toda suggested that the blinking rate is not primarily determined by local corneal and conjunctival factors, instead, the blinking rate is evident when the eyes likely close spontaneously when individuals cannot see comfortably and consciously [70,72]. Some studies have revealed that the spontaneous blinking rate of patients with dry eye is higher than that of the normal population [63,82]. In our study, the spontaneous blinking of the Taiwanese, Japanese and Americans is nearly the same and found in the normal range. Nevertheless, voluntary blinking rate is significantly higher in Taiwanese than other races. The increased frequencies of voluntary blinking were also found in the groups of smart phones and computers users. How can we explain this result？ We suggest that more tears from conscious blinking may refresh the cornea to soothe discomfort symptoms induced by the dry eye condition. In the condition, the tears should be supplied and gained from the voluntary blinks to relieve these associated problems. The report of Kucer is similar to our results [83].

Recent years have seen the dramatic increase in work performed using computers, VDTs and smart phones. Home use of portable information terminals also has risen steadily, with an estimated 28 households in the US having a home computer in 2006. The changeable activity may be accompanied by an increase in health problems and associated ocular symptoms because of VDTs and smart phones use. Even a recent survey has concluded that 66% of children aged 8-17 in most modern countries prefer the Internet if they could have only one medium of entertainment. Another research revealed that Intel estimates that there are close to one billion Internet-connected personal computers through the world. The ocular disorders include eyestrain, tiredness, irritation, blurring sensation, redness, reduced visual acuity, ocular pain, diplopia, and dry eye. Uchino et al. found that the prevalence of dry eye disease is high among VDT users and they selected office workers in 30 large companies for a study database in Japan [23]. Yaginuma et al. firstly mentioned the close relationship among VDTs, dry eye and blinking rate [19]. In our study, the types of computers and smart phones were described as: data entry, call-center operation, interactive operation, programming, monitoring, reading and playing games. Enough blinking is very important and beneficial for long-term periods of computer vision syndrome.

More than half of the smart phone users would complain visual fatigue, dryness, headache, blurring sensations and even “chronic fatigue syndrome”, which may further affect their quality of life. Uchino et al. reported on that the effect of dry eye disease on work performance and productivity in office workers using VDTs and computers [23]. To our surprised, dry eye may lower on-the-job time management, mental performance, interpersonal functioning working hours, tear volume, and physical performance. Annual dry eye deficit productivity losses were estimated to be $6160 per employee when measured by total production and $1178 per employee calculated by wage [23]. Therefore, close observation is needed for children and adults, when using computers and VDTs, especially smart phones. The increased use of near visual tasks may contribute to the development and progression of permanent myopia, which may become another important issue [73].

Moreover, overuse of smart phones has increasing relevance to modern eye care professional with tremendous versatility in daily practice. The fun and convenience of various smart phones attract our concentration and interest; using smart phones look downward, which may also pose other health and public problems such as occupational hazards, neck pain, and unexpected traffic accidents. Consumer electronics (smart phones, i-pads) have become very popular in the past few years. However, the damages to the human body are more valued. In some studies, the pulsed microwaves at 2.45 Hz and 10 mW/cm2 are associated with production of corneal endothelial lesion of the blood-aqueous barrier which may alarm the human eyes. Ocular damage of microwaves was also found at an average specific absorption rate of 0.26 W/kg. Meo et al. reported that 34.59% of problems were related with impaired hearing, earache and/or warm ear, and 5.04% of complaints were related with decreased and/or blurred vision [84]. Further studies showed that the microwaves from the mobile phone could harm people's health including cytogenetic, gene response, DNA damage and central nervous system, reproduction and development damage. When mobile phones with 900-1800 MHz signals are used, the power of this pulsed electromagnetic field reaches a maximum of 250 mW. Exposure to high density microwaves can cause detrimental effects on the eyes and may induce significant biological changes through thermal action. Balik et al. further revealed that peoples using mobile phones may suffer from blurred vision, red eyes, vision disturbance, secretion and inflammation of the eyes, and excessive lacrimation. Furthermore, they found that symptom of massive tear flow in human being was significantly apparent in those who are using mobile phones for at least for 2-4 years (approximately 20-25%). In addition, talking in mobile phones for longer period may increase these symptoms. In our study, some smart phone users sometimes complain about tearing when talking near the ears. We suggest that the microwave from some electronic instruments such as smart phones may impact on the users. However, the exact mechanism should be further investigated.

Because of many confounding factors which may interfere with blinking, we controlled room temperature, humidity, and illumination for standard control in this study. There are also many limitations in the researchers. First, the real separation line between the time in watching TV, utilizing computer and using smart phone which may influence the results needed more detailed evaluation in next studies [71]. Second, the head and body posture when using VDTs, which may also affect the blinking rate were not taken into consideration. For example, vertical head movement significantly influenced the visual symptoms and the subsequent eye blinking [71]. Finally, poor stability, reflection and legibility of VDT screens may cause glare and show positive association with blurred vision, which may disturb normal blinking physiology. Factors such as character, contrast, size, and design were considered to be the major contributors that reduce screen legibility. The association between visual discomfort and screen characteristics, which include screen height, angle, glare and flicker [85]. In this study, we focused on the amount of two different blinking types during various times and electronic utilization conditions. Therefore, many factors require further intervention in the future.

5. Conclusions

Visual symptoms, including eyestrain, headaches, ocular discomfort, dry eye, and blurred vision, are experienced by 64% to 90% of computer users near or at a distance after a prolonged computer use. Computer vision syndrome is associated with the change and completeness of blinking, which are equally significant [88]. Therefore, tear from enough blinking relieves dry eye in any occupations and activities, and enhances visual information, physiological workload, and performance. Ocular complaints and dry eye may be minimized using artificial tears, which showed the same effects as blinking. Deep ocean fish oil with omega-3 fatty acid treatment can improve the ocular fatigue from experienced by computer users [87]. Appropriate ocular relaxation is also highly recommended. Spontaneous blinking rate in healthy humans is reduced to approximately 32%– 55% when these individuals work with VDTs compared with resting condition [88]. Furthermore, incomplete blinking may decrease the amount of tear and induce severe dry eye.

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