Industrial Health, 1994, **32,** 57—66

ORIGINAL ARTICLES

Physiological Indices of Visual Fatigue due to VDT Operation: Pupillary Reflexes and Accommodative Responses

Susumu SAITO[a)1], Midori SOTOYAMA[a)], Shin SAITO[b)]
and Sasitorn TAPTAGAPORN[c)]

a) National Institute of Industrial Health, 21-1, Nagao 6-chome, Tama-ku, Kawasaki 214, Japan
b) Aichi Mizuho College, 86-1 Haiwa, Hiratobashi-cho, Toyota 470-03, Japan
c) Ministry of Public Health, Tivanon Rd., Nonthaburi 11000, Thailand

(Received March 1, 1994 and in revised form June 8, 1994)

Abstract: In spite of the clarification of some significant physiological factors of visual fatigue caused by VDT work, pupillary reflexes have not been studied as to how they are affected after prolonged visual work. This study examined visual function changes objectively in terms of pupillary reflexes and lens accommodative responses after a 4-hr VDT operation task. The relationship between the two functions was also examined. Two measurements in this paper revealed the physiological function changes due to VDT operation. The subjects involved were five students with an average age of 22.6 years. First, near-reflex measurement ascertained decreases in amplitude and the velocity of accommodation function after the visual task. Second, light-reflex measurement revealed a delay of the reflex, an increase in the amplitude of the reflex, and a decrease in pupil size after the visual task. A weak correlation between the decrease in pupil size and accommodation function was found. The occurrence of visual fatigue due to 4-hr VDT operation was also confirmed by CFF measurements and reported subjective visual symptoms in this experiment.

Key words: Pupil — Accommodation — Light-reflex — Near-reflex — Visual display terminals (VDTs) — Critical fusion frequency (CFF) — Eye strain

INTRODUCTION

For over a decade it has been recognized that prolonged work with visual display terminals (VDTs) can cause various health problems such as musculoskeletal disor-

---

[1] To whom correspondence should be addressed.

ders, electromagnetic hazards, visual strain, skin rash, work stress and so forth. Among these problems, visual symptoms were found to be the most frequent complaints of VDT operators by questionnaire surveys1–3). Meanwhile, many researchers had studied some important physiological factors of visual fatigue caused by VDT work in terms of the decrease in accommodative area4), the occurrence of abnormal function of the near triad5), the constriction of pupil size after a visual task6), the variation of pupil size during a visual task7) or a decrease in accommodative power8). Furthermore, subjective visual symptoms and/or visual comfort were found to correlate significantly with the velocity of accommodation9) and with vergence effort10). However, pupillary reflexes have not yet been clarified as to how they are affected after a specific duration of VDT operation. In addition, the relationship between the pupillary reflex and accommodation is still unknown. This study was designed to objectively examine visual function changes in terms of pupillary reflexes and accommodation during and after a 4-hr of VDT task. The relationship between pupil size and accommodation function was also statistically analyzed. In addition, critical fusion frequency (CFF) and subjective visual symptoms were investigated to describe symptoms of visual fatigue.

The nature of pupillary reflexes, namely the light-reflex and the near-reflex, should first be clarified. When the light intensity of a viewed object increases above a threshold value within a certain minimum period of time, the pupil constricts. This constriction of the pupil when light enters the eye is called *the light-reflex.* This reaction of the pupil is a so-called physiological reflex, independent of the intention.

When a person is requested to direct his eyes to an object held close to the face, again, his pupils constrict. This constriction is independent of any change in illumination, and depends on an association among the sphincter pupillae, the ciliary muscle, and the medial recti of the extraocular muscles. It is not a true reflex but an association of these three mechanisms which serves a common purpose, near vision. It is also termed the near-point reaction or the near-reaction of the pupil. In this paper, it is called *the near-reflex.*

MATERIALS AND METHODS

The apparatus shown in Fig. 1 was set up to conduct two measurements, the near-reflex and the light-reflex measurements. The measurement site was an experimental room where a 20 lx horizontal illuminance was maintained on the work surface. For the near-reflex measurement, two slide projectors were used to alternately project Landolt's rings as the far and the near visual targets for the distances of 5 m (0.2 diopter, D) and 0.5 m (2 D), respectively. For the light-reflex measurements, luminances of 34.3 cd/m^2 and 0.34 cd/m^2 were maintained for the high- and the low-luminance targets at a visual distance of 2 D. During the near- and light-reflex measurements, the subjects were asked to sit in front of an auto-refractometer, model AR-1100 (NIDEK Co., Ltd., Gamagori) with chins and foreheads fixed when viewing the visual targets. The auto-refractometer was used for both accommodation measurement and pupil image monitoring. Ten measurements of the visual stimuli were recorded for 7 s each. Pupil images were simultaneously recorded by a video tape recorder (VTR) and analyzed by a Percept Scope, model C 3160 (Hamamatsu Photonics K.K., Hamamatsu) with a spatial accuracy of more than 95% and sampling frequency of 30 Hz. The first and last responses were excluded and the eight time responses to the visual stimuli were averaged and provided for further analysis.

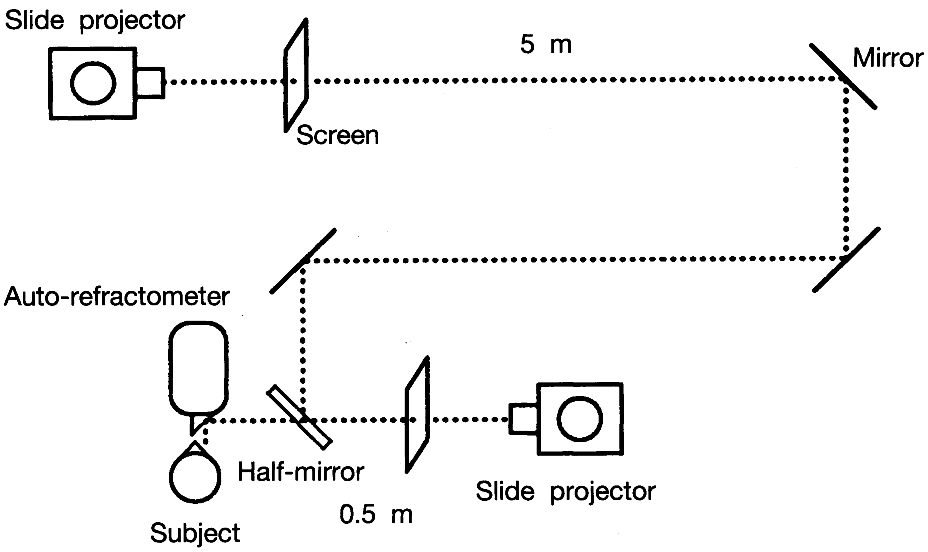

Figure 1. Apparatus showing auto-refractometer and optical pathway set-up for both near-reflex and light-reflex measurements.

The visual task was two 2-hr-long data entry work using a personal computer with a NEC PC-KD 852 display with a screen contrast of 1:14 (34.2 cd/m^2 for the luminance of characters and 2.4 cd/m^2 for that of background) under a horizontal workplace illuminance of 550 lx. The pupillary reflexes and CFF were both immediately examined five times: namely, 1) before the visual task (10.00 am); 2) one hour after starting the task (11.00 am); 3) two hours after starting the task (12.00 am); 4) after a one hour lunch break (1.00 pm); 5) and after four hours of performing the task (3.00 pm). During the lunch break, each subject was asked to take a rest without intensive visual work such as reading. The monocular right eye was examined during the study. Finally, each subject answered a self-reporting questionnaire concerning their eye symptoms both before and after the experiment.

The subjects involved were five students, two females and three males. Their ages ranged from 22 to 23 years old, averaging 22.6 year. All subjects had normal eyes with appropriate refractive corrections.

The statistical analyses used in this study were the paired *t*-test, the analysis of variance (ANOVA), and correlation analysis.

RESULTS

1. *Lens accommodation*

Fig. 2 illustrates the analysis of accommodative response in terms of latency (D), velocity of accommodation (A), amplitude of accommodation (C), latency of relaxation (E), and velocity of relaxation (B). Lens accommodation was analyzed from the near-reflex measurement. The eight time accommodative responses to stepwise stimuli were averaged by the computerized data processor. The results are shown in Fig. 3, as percentages. It is clearly seen that the amplitude, the velocity of accommodation, and the velocity of relaxation decrease during the first 2-hr VDT task, then recover by the end of the one-hour lunch break, and then decrease again by the end of the second 2-hr VDT task excepting the velocity of accommodation, which increases slightly. The velocity of lens accommodation could have been affected by individual differences, given that two out of five subjects had an increase in the velocity of accommodation after the second 2-hr VDT task. Individual differences among the five subjects in these three indices could be expressed by the coefficient of variance. The coefficients of variance for all measurements of velocity of accommodation, velocity of relaxation, and amplitude were calculated to be 38.6%, 46.0% and 32.2%, respectively. In examining the latency and the latency of relaxation, no consistent effect was found in this study. However, it was apparent from the results for all subjects that the latency of relaxation lasted a slightly longer time than the latency of accommodation.

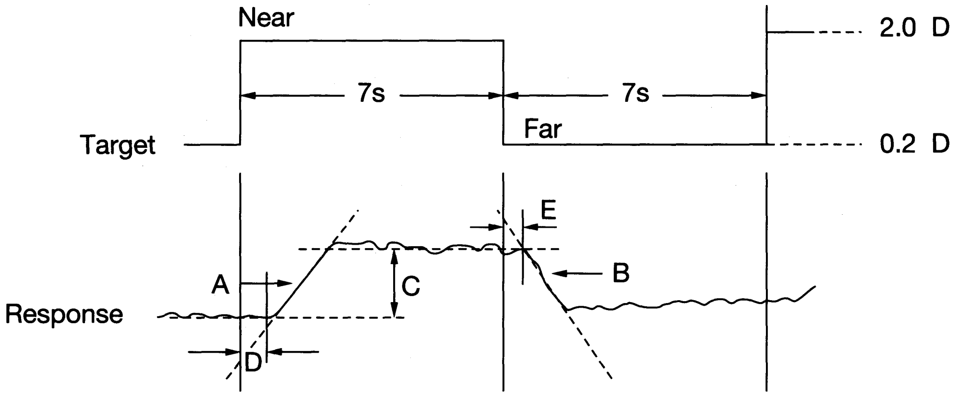

Figure 2. Analytical terms of accommodative response of the eye used in this study. A) velocity of accommodation (D/s); B) velocity of relaxation (D/s); C) amplitude of accommodation (D); D) latency (s); and E) latency of relaxation (s).

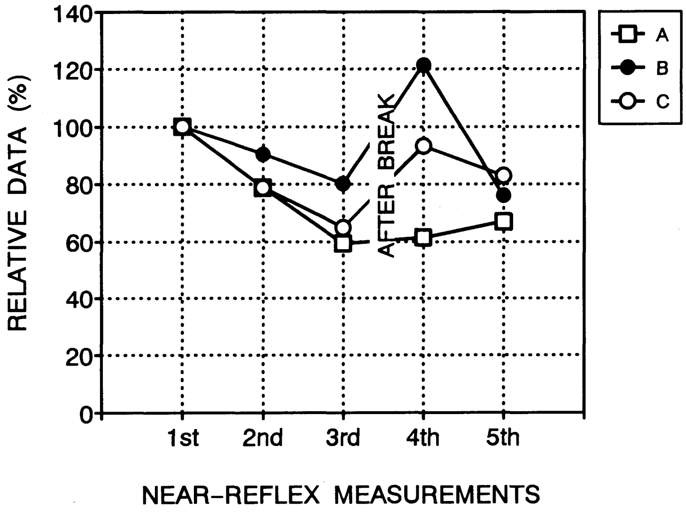

Figure 3. Average accommodative responses by percentage for five subjects showing decreases in the velocity of accommodation (A), the amplitude of accommodation (C), and the velocity of relaxation (B) after each VDT task period.

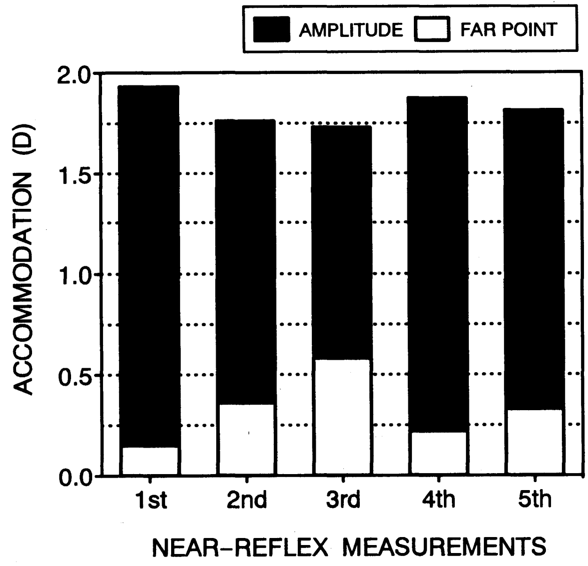

Figure 4. Decreases in the amplitude of accommodation obtained by the nearer far-point and the farther near-point after each period of VDT task.

Concerning the accommodative power, or the amplitude of accommodation, it was found that after each period of VDT task, the accommodation to the far-point became closer while the accommodation to the near-point became farther away, resulting in a decrease in the amplitude of accommodation. It recovered after the lunch break and decreased again after the second 2-hr task, as shown in Fig. 4 as the average of all five subjects.

ANOVA was used to analyze whether individual differences and VDT working time significantly influenced accommodative responses. The results show that the amplitude and the velocity of accommodation are affected by both individual differences and the working time ($p < 0.01$ and $p < 0.05$, respectively). The latency and the latency of relaxation are influenced by individual differences ($p < 0.01$), but not the number of working hours ($p > 0.05$), while the velocity of relaxation was not influenced by either ($p > 0.05$). By paired *t*-test analysis, only the amplitude and the velocity of accommodation were found to be significantly decreased after the VDT task ($p < 0.05$).

In the light-reflex measurement, as the static stimuli on the accommodation system, the amplitude of accommodation was also analyzed but no consistent change was found for the average of the five subjects. In other words, no effect of fatigue on the accommodation system could be discerned from the light-reflex measurement.

2. *Pupil*

The results of the pupillary reflex measurements, the near-reflex and the light-reflex measurements were analyzed in terms of the pupil diameter (D_1), the amplitude of pupillary constriction (D_2), latency (T_1), the time to half constriction (T_2), the time to maximum constriction (T_3), and the recovery time to 63% of D_2 from constriction (T_4) as shown in Fig. 5.

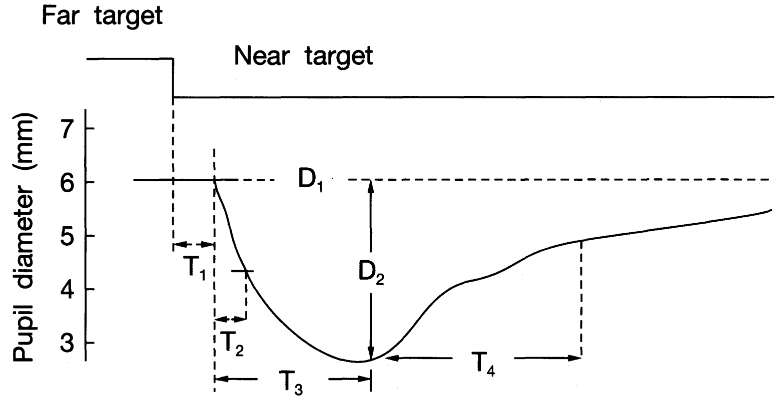

Figure 5. Analytical terms of the pupillary reflex used in this study. D_1) pupil diameter before constriction (mm); D_2) amplitude of pupillary constriction (mm); T_1) latency (s); T_2) the time to half constriction (s) ; T_3) the time to maximum constriction (s); and T_4) the time needed to recover to 63% of D_2 (s).

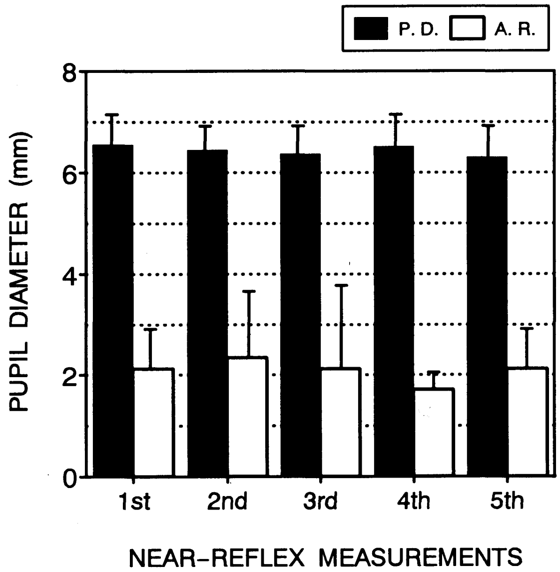

Figure 6. Average and SD of the pupil diameter (P.D.) and the amplitude of the reflex (A.R.) for all five subjects in the near-reflex measurement. P.D. was found to decrease significantly after the VDT task while A.R. had a tendency to increase.

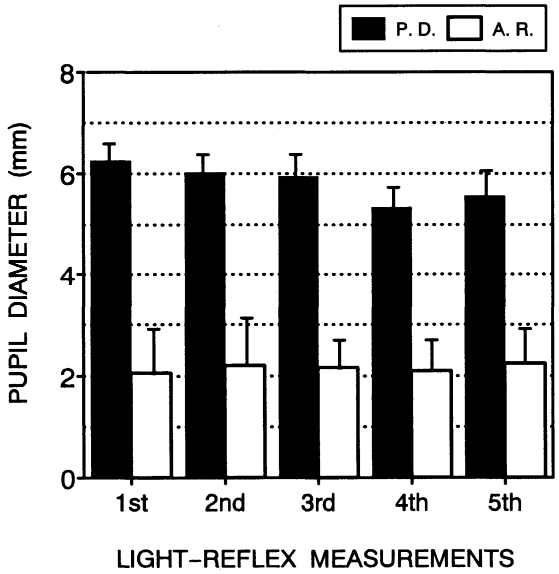

Figure 7. Average and SD of the pupil diameter (P.D.) and the amplitude of the reflex (A.R.) for all five subjects in the light-reflex measurement. P.D. was found to decrease significantly after the VDT task while A.R. had a tendency to increase.

From the two pupillary reflex measurements, the average pupil diameter for the five subjects became smaller after each period of visual workload while the amplitude of pupillary constriction increased slightly as shown in Figs. 6 and 7. It was recovered after one hour break (the 4th measurement) in the near-reflex measurement but not in the light-reflex measurement. In addition, after the second 2-hr VDT task, pupil diameter (D_1) was found to be significantly smaller than that before the visual task in both the near- and light-reflex measurements as determined by paired *t*-test analysis ($p < 0.05$). The increase in the amplitude of pupillary constriction (D_2) from both measurements was not found to be statistically significant. T_1 showed no consistent change after each period of the visual task in the light-reflex measurement. Meanwhile, T_2, T_3, and T_4 became longer after the second 2-hr visual task but proved not to be statistically significant ($p > 0.05$). However, there was a tendency, in this study, for the velocity of pupillary reflexes and the recovery time to be delayed due to visual workload.

3. *Relationship between pupillary reflexes and lens accommodation*

Linear regression analyses were used to examine the relationship between accommodative and pupillary reflexes using the mean data from the five subjects. The decrease in the amplitude of accommodation was found to have a weak correlation with the constriction of pupil diameter for each near-reflex measurement, with $r = 0.68$, but was not statistically significant ($p > 0.1$). The decrease in the velocity of accommodation also correlated with the constriction of pupil diameter in the light-reflex measurement, with $r = 0.72$, but again it was not statistically significant ($p > 0.1$). The amplitude and the velocity of both pupillary reflexes were not found to correlate with either the amplitude or the velocity of accommodation through the course of the visual task.

4. *CFF and subjective eye symptoms*

The CFF of each subject was examined five times/measurement both before and after each period of the visual task. Table 1 shows the decrease of the CFF values in each subject after each successive measurement. The CFF inversely increased in three subjects, resulting in an increase of CFF at the fifth measurement as the average of five subjects. However, the CFF after the visual task was still lower than before the visual task.

To subjectively evaluate eye symptoms induced by the VDT work, all subjects were asked to answer a self-reporting questionnaire concerning eye symptoms both before and after the two 2-hr VDT tasks. The results show that there were no eye symptoms before the task in any of the subjects, but after the visual task they developed symptoms in all seven categories of eye symptoms as shown in table 2.

DISCUSSION

The decrease in the amplitude of the accommodative response after VDT workload observed in this study supports the results of Östberg (1980)[8]. That is, the accom-

Table 1. CFF by subject and measurement time during VDT task.

Subjects	CFF measurements (Hz)				
	1st	2nd	3rd	4th	5th
1	39.6	37.0	35.6	34.0	35.8
2	37.2	36.0	35.6	36.2	35.2
3	34.0	32.8	32.6	33.0	32.8
4	34.6	33.0	31.2	31.4	32.4
5	37.4	39.6	39.0	38.8	40.2
Average	36.6	35.7	34.8	34.7	35.3

Table 2. Distribution of self-reported responses by five subjects to eye symptoms before and after the visual tasks. Level of severity is classified by 1 to 4 (low to high).

EYE SYMPTOMS	BEFORE	AFTER TASK				
	SEVERITY	SEVERITY				
	NONE	NONE	1	2	3	4
1. Eye fatigue	5	0	1	2	1	1
2. Eye pain	5	4	1	0	0	0
3. Tearing sensation	5	2	2	0	1	0
4. Eye dryness	5	2	1	1	0	1
5. Headache	5	4	0	0	0	1
6. Blurred eye	5	2	1	0	2	0
7. Blinking more frequently	5	0	4	0	1	0

modation becomes more myopic for distant stimuli and more hyperopic for near stimuli. In the present study, both the amplitude and the velocity of accommodation are considered to be the important factors for the evaluation of accommodation function concerned with visual fatigue, especially in the near-reflex measurement, i.e., the responses to dynamic stimuli. For static stimuli, no accommodation function response could be examined as in the light-reflex measurement.

The constriction of pupil size and the increase in the amplitude of pupillary reflexes after the two 2-hr-long VDT tasks may be caused by spasms of the sphincter pupillae and the ciliary muscles which are regulated by the parasympathetic nervous system. This suggests that visual fatigue can lead to an unbalanced excitation of sympathetic and parasympathetic nervous systems. It was concluded from the study that the prolonged VDT task caused pupil size constriction and the tendency for increases in the amplitudes of pupillary reflex or constriction. The constriction of pupil size after VDT task found in this experimental study agreed with the results obtained in the field study of real VDT workers by Hirose *et al.* 1991[6)].

The present study ascertained the effects of visual fatigue due to a VDT task on the accommodation and the pupil systems. On the other hand, in the investigation of eye movements by Saito (1992)[11)], it was found that the quantitatively measured characteristics of eye movements were independent of the load and duration of visual task. In other words, no visual fatigue can be found from the intensive eye movements, and the eye movement characteristics can not be as an index of visual fatigue.

Due to the fact that both the pupillary and accommodative functions are highly variable among different age groups[9)], the subjects in this study (22–23 years-old) were selected because they are highly sensitive to accommodative response. The study could not corroborate any significant relationship between the accommodation function and the pupillary reflexes. This might depend on the relatively small number of subjects involved in this study. However, the accommodation function was found to have a weak correlation with pupillary constriction. Therefore, further study is necessary to confirm this conclusion. The CFF patterns and the results of subjectively reported eye symptoms confirmed the existence of visual fatigue due to the two 2-hr-long VDT workload used in this study. In conclusion, both the accommodation function and pupil size are considered to be important physiological indices for the evaluation of visual fatigue due to work.

REFERENCES

1) Ghiringhelli L. Collection of subjective opinions on use of VDUs. In: Grandjean E, Vigliani E, eds. Ergonomic Aspects of Visual Display Terminals. London: Taylor & Francis, 1980; 227–31.
2) Smith MJ, Stammerjohn LW, Cohen Barbara GF, Lalich Nina R. Job stress in video display operations. In: Grandjean E, Vigliani E, eds. Ergonomic Aspects of Visual Display Terminals. London: Taylor & Francis, 1980; 201–10.
3) Gobba FM, Broglia A, Sarti R, Luberto F, Cavalleri A. Visual fatigue in video display terminal operators: objective measure and relation to environmental conditions. International Archives of Occupational and Environmental Health 1988; 60: 81–7.
4) Takeda T, Fukui Y, Iida T. Influence of CRT refresh rates on accommodation aftereffects. Work With Display Units 86. North-Holland: Elsevier, 1987; 474–82.
5) Ishikawa S. Examination of the near triad in VDU operators. Ergonomics 1990; 33 (6): 787–98.
6) Hirose N, Akiya S, Saito Sh, Taptagaporn S, Saito S. Pupillary fatigue caused by VDT operation. Proceedings of Japanese Association of Industrial Hygiene (in Japanese) 1991; 153.
7) Taptagaporn S, Saito S. How display polarity and lighting conditions affect the pupil size of VDT operators. Ergonomics 1990; 33 (2): 201–8.
8) Östberg O. Accommodation and visual fatigue in display work. Ergonomic Aspects of Visual Display Terminals. London: Taylor & Francis, 1980; 41–52.
9) Saito S, Taptagaporn S, Salvendy G. Visual comfort in using different VDT screens. International Journal of Human-Computer Interaction 1993; 5 (4): 313–23.
10) Tyrrell RA, Leibowitz HW. The relation of vergence effort to reports of visual fatigue following prolonged near work. Human Factors 1990; 32 (3): 341–57.
11) Saito S. Does fatigue exist in a quantitative measurement of eye movements? Ergonomics 1992; 35 (5/6): 607–15.