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Effects of vertical viewing angle and eye blink rate during computer work

Sol Elvira Solorzano
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EFFECTS OF VERTICAL VIEWING ANGLE AND EYE BLINK RATE DURING
COMPUTER WORK

A Thesis

Presented to

The Faculty of the Graduate Program in Human Factors/Ergonomics

College of Graduate Studies

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Sol Elvira Solorzano

May 1998

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ABSTRACT

EFFECTS OF VERTICAL VIEWING ANGLE AND EYE BLINK RATE DURING COMPUTER WORK

by Sol Elvira Solorzano

The effects of vertical viewing angles and eye blinking rate during computer work were investigated. Twenty subjects read from a computer screen set at viewing angles 15° above eye level, eye level, 15° below eye level, and 30° below eye level. Eye blinks during tasks were measured by electrooculography. Subjective ratings on visual and musculoskeletal strain were obtained. Test hypotheses were: (a) blink rate does not change with variations of viewing angle, (b) blink rate does not change with time-on-task, and (c) there is no interaction between viewing angle and time-on-task effects. The results indicated that blink rate increases as the viewing angle approaches eye level, and that blink rate increases with time-on-task. No significant interaction was found between viewing angle and time-on-task. Results and subjective ratings support recommendations of VDT viewing angle range near 15° below eye level.

DEDICATION

I dedicate this thesis to my grandmother, Mrs. Francisca Reyes, for all the love and help she has given me throughout my entire life. She is very special to me among the many special persons in my life. I would also like to dedicated this thesis to my parents for their love and encouragement, and for instilling in me a drive for education and knowledge since my early years.

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TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
INTRODUCTION	3
METHOD	22
SUBJECTS.....	22
DESIGN	22
INSTRUMENTATION.....	23
PROCEDURE	25
RESULTS	29
DISCUSSION	37
CONCLUSION.....	44
REFERENCES	45
APPENDICES	50

LIST OF TABLES

<u>TABLE</u>		<u>PAGE</u>
1	Blink Rate (blinks/minute) Statistics	32
2	ANOVA Results (Viewing Angle x Time-on-task)	33

LISTS OF FIGURES

<u>FIGURE</u>		<u>PAGE</u>
1	Experimental set up according to viewing angle	28
2	Overall mean blink rate against viewing angle	34
3	Overall mean blink rate against time-on-task	34
4	Mean blink rate by viewing angle against time-on-task	35
5	Mean self-reported visual strain against viewing angle	35
6	Mean self-reported muscular strain against viewing angle	36

Effects of Vertical Viewing Angle and Eye Blink Rate During Computer Work

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Abstract

The effects of vertical viewing angles and eye blinking rate during computer work were investigated. Twenty subjects read from a computer screen set at viewing angles 15° above eye level, eye level, 15° below eye level, and 30° below eye level. Eye blinks during tasks were measured by electrooculography. Subjective ratings on visual and musculoskeletal strain were obtained. Test hypotheses were: (a) blink rate does not change with variations of viewing angle, (b) blink rate does not change with time-on-task, and (c) there is no interaction effects on blink rate between viewing angle and time-on-task. The results were blink rate increases as the viewing angle approaches eye level, and blink rate increases with time-on-task. No significant interaction was found between viewing angle and time-on-task on blink rate. Results and subjecting ratings support recommendations of VDT viewing angle range near 15° below eye level.

Effects of Vertical Viewing Angle and Eye Blink Rate during Computer Work

Due to an increasing awareness in how vision affects work productivity in the workplace, there has been a growing interest in the field of visual ergonomics. Research on vertical gaze direction, in particular, is growing since it can be a significant factor leading to complaints of visual discomfort (Sotoyama, Villanueva, Jonai, & Saito, 1995). The type of visual task performed (inspection vs. monitoring), and location of the visual stimuli (focal distance, vertical, and horizontal location) have been found to have a direct impact on an individual's work performance. Vision professionals have tied these complaints of visual discomfort to the use of video display terminals (VDTs), and their effects on how quickly tears are evaporated. These professionals explain that visual discomfort is partly due to the faster evaporation of tears, which can result in eye dryness. Due to the location and size of text, reading from a computer screen requires the eyes to be opened wider than normal, and the wider the eyes are opened, the faster tears are evaporated. The evaporation of tears is exasperated by a decreasing in eye blinking, which stems from the concentration required during computer work. In addition, environmental factors such as humidity, office temperatures, lighting sources, airflow, and pollutants are also believed to contribute to visual discomfort, although to a lesser degree (Ponder & Kennedy, 1927; Thygesen, Bach, Molhave, Pedersen, Prause, & Skov, 1986).

Specifically, the purpose of this study was to investigate how changes in the vertical viewing angle effect the eye-blinking rate during computer work. The hypotheses to be investigated in this study were: (a) blink rate does not change with

variations of viewing angle, (b) blink rate does not change with time-on-task, and (c) blink rate does not change due to the interaction between viewing angle and time-on-task. It was of interest in this study to determine if the vertical position of the VDT screen affects blinking rate. By understanding which vertical position is best, a position that promotes blinking while providing comfortable postures can become more widely used.

The importance of addressing VDT related eyestrain is imminent as the rate of VDT users and reports of visual discomfort continue to increase. Over 50% of the US work force is estimated to use VDTs regularly, approximately 60 to 65 million workers. Furthermore, it is estimated that over 20 million people use VDTs at home for business, and over 17 million are using VDTs in educational and training institutions (Leavitt, 1995). By the year 2000, the number of computer users in the United States' work force is expected to reach 75 % (Costanza, 1994). Not only are the number of computer users increasing rapidly, but the amount of hours per day spent with computers at work and at home are also growing at a dramatic rate. Previous studies show that as people spend more time using a VDT, complaints of visual and physical discomfort increase (Resko & Mansfield, 1987). Followed by musculoskeletal related symptoms in back, arm, shoulder, wrist, and neck, visual related problems constitute the highest number of complaints in the work place.

By better understanding the effects of the viewing angle on visual strain, VDT related eyestrain could be decreased through the development of numerous applications. These applications can be included the design of products such as eyewear, and visually activated devices (i.e., input devices). Designing with a motive of increasing eye

blinking while decreasing dryness can help reduce the incidence of eyestrain in the workplace. In addition, vision comfort among computer users can have a positive impact on productivity and the well being of workers.

Like our visual system, the visual strain phenomenon is extremely complex. There are a great number of factors involved with visual strain including the physical, psychological, environmental, and individual visual characteristics. Therefore, the study of visual strain requires the utilization of many of the approaches demonstrated through the studies and theories currently available. For the purpose of this study, this review concentrates on several key elements related to dry eye symptoms caused by VDT use: near visual work, evaporation of tears, viewing angles, and blink rate. Related musculoskeletal factors are also discussed since they play an intricate role in human comfort.

VDT Use and Eye Strain

When performed for prolonged periods of time, near visual activities often result in reduced visual performance and discomfort. The fact that near visual activities often strain the eyes can be attributed to the manner, in which, the human eye evolved. Our eyes have evolved over millions of years with the primary purpose of scanning and fixating on objects at long distances. When scanning and fixating at long distances, the ocular motor system dynamically accommodates, diverges, and converges images. Eye movements become closely coupled with head, neck, and body movements, which are also dynamic in nature. On the other hand, focusing on objects at near distances was meant to be done only intermittently (Lie & Watten, 1994). As a result, in order to

maintain focus during near visual work, the size of the visual field is decreased drastically and the dynamic muscular activities of the eyes are converted into static activity. At the same time, the muscular activities of the head and body also become static, eventually leading to strain and fatigue.

During the last century, rapid technological changes from agricultural, to industrial, to informational bases have resulted in a dramatic increase in the amount of visual demands workers encounter. Before the onset of computers, workers gathered information from various sources including face-to-face communication with peers and customers. Over the past two decades, workers have increasingly begun to rely on computers as the primary productivity and informational tool. As a result, this dependency has led to a reduction in the variety of tasks found in most work environments. Instead of gathering information through face-to-face communication, most of the required information can now be easily accessed by the computers, which are readily available at the worker's cubicle or workstation. Therefore, throughout the workday, vision is directed primarily to objects at short distances such as VDTs, documents, display panels, and input devices. For example, in 1980, Laville found that data entry operators directed 70% of their visual attention to source documents, 18% to VDT, and 10 % to keyboard. Even the "interactive" operators, who had more variable, still faced demanding visual tasks which caused them to direct 28% of their visual attention to source documents, 30% to VDTs, 15% to the keyboard, and 27% to other tasks (Hamilton, 1996). With the growing number of internet and intranet systems available, one can expect the percentage of time spent with VDTs to continue to increase.

The fact that near visual activities are taxing on the ocular motor system is well known. However, the use of VDTs has brought up particular concerns since VDTs are believed to intensify visual problems in the workplace. Such concerns have stemmed from studies showing that workers using VDTs have more visual-related complaints than those not using VDTs. For example, Smith, Cohen and Stammerjohn (1981) concluded that over 90% of VDT users complained of eyestrain, compared to 60% of non-VDT users. Furthermore, 71% of VDT users complained of blurred vision, while only 35% of non-VDT users experienced this problem. Several other studies show evidence of physiological changes in the eyes during VDT use. In particular, a study conducted by Lie and Watten (1994), involving 18 subjects, found that an experimental group performing a 3 hour text-editing task with a keyboard and VDT (near distance) had significantly higher post-task myopia, reduced ciliary, and vergence capacity when compared to the control group. Unlike the experimental group, the subjects in the control group performed the same task, but were not placed in front of VDTs. Instead, they were instructed to listen to audiotapes and focus on the landscape outside the window (long distance). The findings from this study imply that eye muscles become strained or fatigued by work that requires focusing at closer distance for prolonged periods of time.

Evidence of increased visual strain caused by VDT use has also been recorded clinically. A survey conducted at the UC Berkeley's VDT Clinic (Sheedy & Parsons, 1990), shows that at least 10 million patients consulted eye care specialists for VDT-related eye symptoms in the year 1990. As the general public becomes more aware of visual related symptoms at work, the number of reported cases is expected to rise

dramatically. According to the survey, the most frequently occurring symptoms in descending order are eye strain, headaches, blurred vision, temporary myopia (nearsightedness), dry or irritated eyes, neck/back pain, photophobia (sensitivity to light), double vision, and after images. Although there is no evidence to indicate that VDT use causes long term changes to the eyes, one can not help but wonder about the potential for long-term effects.

VDT Use and Muscular Strain

Musculoskeletal related occupational injuries (mostly referred as cumulative trauma disorders or CTDs) have shown a marked increase over the last two decades. By 1990, they had accounted for over 50% of all occupational injuries in the United States. VDT workers have reported symptoms primarily in the upper extremities, neck, and shoulders (Faucett & Rempel, 1986). As mentioned earlier, factors like the position of input devices and VDTs, the level of concentration involved with computer work, and the resulting awkward and highly static postures assumed by workers may all lead to muscular strain. In the previously discussed study by Lie and Watten (1994), a significantly higher number of subjective complaints about discomfort were expressed by subjects performing the VDT task. The experimental group (VDT task) experienced orbital aching, neck pain, shoulder pain, and back pain, while the control group (non-VDT task) only reported significant neck pain.

When we attempt to understand VDT-related strain, the cervical spine, the neck, and shoulder muscles are of primary concern (as opposed to the upper extremities primarily affected by use of input devices) due to the fact that, when viewing a VDT, eye,

neck, and head movements are all required to work collectively to gaze horizontal or vertically. As a result, the visual angle, and therefore, the neck angle are almost entirely determined by the location of the VDT. Furthermore, clinical findings indicate that as the required degree of neck bending increases, the amount of pain will grow. This pain in the cervical area is more likely to result from the flexing and rotation of the neck (Hamilton, 1996). Increased levels of strain on neck muscles directly caused by neck flexing have been found in a few studies. For example, Hamilton (1996) found muscular strain (in percent of maximum voluntary contraction, %MVC) to be significantly higher for the left and right extensor muscles of the neck during a reading task which placed source documents at 30 degrees below eye level. The mean %MVC for left and right extensors at 30 degrees below was 3.52 ± 3.61 and 4.02 ± 4.0 , respectively. While at eye level, the mean was measured to be 2.22 ± 2.78 and 1.73 ± 2.34 , respectively. In another study by Villanueva, Jonai, Sotoyama, Hisanaga, Takeuchi, & Saito (1997), muscle activity was found to increase in the neck extensors and the trapezius pars descendens muscles as the degree of neck flexion increased. Flexed neck extension has also been found to lead to higher stress in the cervical spine than at the upright posture (Villanueva, Sotoyama, Jonai, Takeuchi, & Saito, 1996).

Viewing Angles

Villanueva et al. (1996) defined viewing angle as the angle formed by the horizontal plane and the line between the subject's eye and the visual target. Furthermore, the viewing angle is comprised by a vertical gaze angle component and a neck angle component. For example, when viewing a VDT at 30 degrees below eye

level, the 30 degrees is made up of the vertical gaze (eyes) angle and the neck angle. In this study, only the viewing angle was controlled. Vertical gaze and neck angles were expected to interact dynamically to achieve the desired viewing angle. Controlling either the vertical gaze or neck angle would have required postural restrictions that would have affected the resulting eye blink rate, and would have also made the study less applicable to real work settings.

Villanueva et al. (1996) investigated the body postures of 10 subjects at the five different VDT heights of 31.5 in., 35.4 in., 39.3 in., 43.3 in., and 47.2 in. These heights measured the distance from the floor to the middle of the VDT screen. Findings illustrated that the neck angle (from Reid's line) and thoracic bending (formed between C7, angles inferior scapula, and iliac crest) were affected significantly by changes in VDT height. Reid's line extends from the outer canthus to the center of the ear canal (Sotoyama, et al., 1995). As the VDT height increased, the neck angle increased, causing the neck and head to become more erect. Similarly, greater height of the VDT screen resulted in a straightening of the upper back. More specifically, the study found that the vertical gaze and neck angle components of the viewing angles changed significantly with screen height. During the taller screen heights, the neck angle component was higher than the gaze angle. When subjects encountered the lower screen heights, the gaze angle component was higher than the neck angle component in producing the resulting viewing angle. This suggests that the vertical gaze direction is limited to viewing angles above eye level. Therefore, greater neck inclination is required to look above eye level than is required to look below. These findings were supported by the fact that there were

no remarkable effects on vertical gaze angles corresponding to VDT height changes from 39.3 in. to 43.4 in., and from 43.3 in. to 47.2 in. At these heights, the changes in viewing angle were credited to the neck angle components. Trunk inclination and pelvic angle did not change significantly in response to screen height.

The subjective assessments of discomfort during VDT use at various viewing angles have been somewhat debatable to this date. De Wall, Van Riel, Aghina, Burdof, & Snijders (1992) concluded that the preferable direction of view was located at 15 degrees toward the middle of the screen above the horizontal level (i.e., place the middle of the monitor at eye level) rather than 15 degrees below (Lu & Aghazadeh, 1993). In their own study, Lu and Aghazadeh argued that subjects feel more comfortable when the VDT screen is located at eye level, and least comfortable when placed above eye level (9.8 in.). At the same time, Leavitt (1995) recommended that the gaze line be between 15 to 45 degrees below the horizontal eye level. Although muscular discomfort was not a key variable of interest in this study, attempts were made to establish levels of muscular discomfort in the neck, shoulders, upper and lower back throughout the different viewing angles.

Ocular Surface Area during VDT Work

An increase in the ocular surface area (OSA) exposed during VDT use is believed to be a major contributor to reports of discomfort due to dry eyes. The OSA is defined as the area in the sclera and the cornea that are exposed when the eye is opened. This area is normally covered with a tear film composed of lipid, aqueous, and mucin layers which are spread by each blink of the eye (Tsubota & Nakamori, 1993). As the eye opens

wider, the tear film begins to evaporate faster between blinks, exposing the eye to irritants such as dust, heat, airflow, and dryness. Sotoyama et al. (1995) reported that OSA is directly affected by vertical gaze angle since “The human eyeball and the upper eyelid move together in what is known as a physiological synergic action” (p. 44).

Sotoyama et al. (1995) performed a multiple study in which OSA was measured as a function of vertical gaze angle and type of task (VDT versus non-VDT work). In the first experiment, video image analysis was used on six subjects to measure the amount of OSA (cm²) exposed when the visual target was moved vertically, ranging from 60 degrees below to 20 degrees above Reid's line. According to results, the OSA increased continuously due to changes in vertical gaze from 50 degrees below to 10 degrees above Reid's line:

$$\text{OSA (cm}^2\text{)} = y = 0.039x_1 + 3.36$$

where x_1 = vertical gaze angle away from Reid's line

There was a high correlation coefficient, $r = 0.99$. This derived equation was then used to estimate the respective OSA based on the mean vertical gaze angles of zero degrees from Reid's line for VDT workers, and of 40 degrees below for non-VDT workers (obtained from a previous study by Saito, Sotoyama, Suzuki, Saito, & Taptagaporn, in 1993). The estimated OSA for VDT workers (3.4 cm²) was twice as large as that for non-VDT workers (1.8 cm²).

They conducted a second study to confirm their previous predictions. They measured the resulting OSA as subjects completed five different visual tasks: a) word processing with VDT, b) drawing a picture with VDT and mouse, c) reading a book, drawing a picture by hand, and writing. The mean OSA measured during the word processing task was $2.1 \pm 0.9 \text{ cm}^2$. When drawing a picture with a VDT and mouse, it measured as $2.6 \pm 0.2 \text{ cm}^2$. While reading a book, the OSA was $1.9 \pm 0.3 \text{ cm}^2$, when drawing a picture by hand, it was $2.1 \pm 0.3 \text{ cm}^2$, and when writing, the OSA was $2.0 \pm 0.3 \text{ cm}^2$. Although the overall OSA for VDT tasks did not turn out to be twice as large as that of non-VDT tasks, the results showed a true difference in the amount of OSA exposed.

In an earlier study performed by Tsubota and Nakamori (1993), the OSA of 104 offices workers were measured while workers were relaxed ($2.2 \pm 0.4 \text{ cm}^2$), reading a book ($1.2 \pm 0.4 \text{ cm}^2$), and reading text from a VDT ($2.3 \pm 0.5 \text{ cm}^2$). In their study, while workers read from VDTs, the OSA was nearly twice as large as the OSA measured while workers read from books. At the same time, the OSA measured while reading from VDTs was to be almost the same as that measured during the relaxed conditions. This can be explained by the fact that the gaze angles for the two activities are about equal. The study also measured eye blinks, and obtained a mean blink rate of 27 ± 9 blinks/min during the relaxed gaze, 10 ± 6 blinks/min while reading a book, and 7 ± 7 blinks/min while reading text from a VDT. The changes in blink rates proved to be significant between the three tasks. However, because the study was not clear on the location of the visual targets, we are not sure whether the location, along with the changes in tasks,

contributed to the results. In other words, we can not assume from the study that reading from VDTs will always yield lower blink rates without considering the how the location of the target effects blink rates. On the other hand, the effects on the OSA by viewing angles or target vertical location have been firmly established.

Eye Blinking and Tear Evaporation

Blinking serves multiple functions, but is primarily necessary for the formation and maintenance of the tear film that lubricates the cornea, flushes out foreign objects (i.e. dust), and contains antibacterial solutions that prevent cornea infections (Fried, 1980). Blinks, for the most part, are involuntary. They sometimes occur as a defense mechanism, known as reflex blinking, to protect the eye from potential environmental hazards, such sudden loud noises and bright lighting. This study will mostly focus on involuntary blinking during work with VDTs.

The amount of tear volume in the eye is affected by the frequency of eye blinking. The tear film protecting the eye is roughly 7 micron thick. Thirty to 40 percent of this film evaporates in about 30 seconds (Yaginuma, Yamada, & Nagai, 1990). Because this film evaporates so quickly, if blinking does not occur once every 30 seconds, eyes are likely to experience dryness. The interval between the last blink and the appearance of the first randomly distributed dry spot is known as the tear break-up time (TBUT). A normal TBUT interval usually lasts 10 seconds or more. A TBUT of less than 10 seconds is considered abnormal (Yaginuma et al., 1990), and individuals with abnormal TBUT are more likely to suffer from dry eye symptoms. In order to measure the effect VDTs may have on TBUT, Yaginuma et al. measured and compared the tear volume (in

mm.) and TBUT of workers ($n=7$) who used VDTs on a regular basis, for an average of 4 hours per day, to those not using VDTs ($n=4$). The subjects were analyzed before, during, and after they were exposed to VDTs for 2 hours. They found that for the non-users group tear volume decreased only during VDT use, while tear volume for regular VDT users was already decreased even before the VDT task was performed. Subjects who used VDTs regularly had a lower average tear volume of 10mm prior to VDT use, while the non-users group averaged 20mm of tear volume. During the task, tear volume was measured every 30 minutes, and showed a decrease to about 10 -13 mm for non-users. Thirty minutes after the end of VDT task, the non-users' volume increased back to 18 mm. On the other hand, the tear volume of regular VDT users increased slightly to 10 - 14 mm during the task, and then decreased back to 11 mm 30 minutes after the VDT task. TBUT for both groups were measured 3 hours after VDT operation. For the non-users, the average TBUT was 17.6 ± 2.8 seconds, while for VDT user group, it was 6.5 ± 3.0 seconds. These findings suggest that prolonged use of VDTs can lead to a reduction in tear volume and to faster tear break-up time.

Additionally, blink rate was measured on two subjects from each group. While both groups showed a marked decrease in blink rate during the VDT task, the mean blink rate from the non-users was much lower than that of regular VDT users. Based on the faster tear evaporation time and higher blink rates found for the VDT users, Yaginuma et al. (1990) suggested that continuous use of VDTs may have a cumulative effect on users by decreasing their tear volume and increasing their tear evaporation rate, even when not operating a VDT. Removal of the oily layer of the tear film could occur as a result.

According to Yaginuma et al. the tear evaporation rate can be 4 to 10 times faster when this oily layer is removed. Hence, they suggested that the higher blink rate in the VDT users group could be in response to accelerated tear evaporation due to continuous use. Due to the small number of subjects and lack of statistical data available from this study, it is not known if the differences among the two groups are statistically significant. However, their findings suggest an interesting approach to potential interdependencies between tear volume and blink rates.

Corneal Dryness and Blinking

The theory of interdependency between tear volume and blinks rates has been investigated in several studies in the field of optometry. One such study, performed by Collins, Seeto, Campbell, and Ross (1989), supports the theory that interdependency exists between corneal sensitivity and blinking. In addition, the study follows the hypothesis that corneal nerves detect changes in tear volume, which subsequently, initiates blinking. The study measured the blink rates, central and peripheral corneal sensitivity, and lid margin sensitivity of nine young adults with normal vision, prior to, and after the application of a topical corneal anesthetic (Alcaine). Blink rates were measured in 3-minute periods, while the subjects engaged in conversation. After the application of the anesthetic, findings showed blink rates to be significantly lower ($\bar{M} = 17.2 \pm 6.6$ blinks/min), than before the anesthetic was applied ($\bar{M} = 24.8 \pm 10.2$ blinks/min). Although the study could not determine exactly how corneal sensitivity affects blinking, it implies that it does play a role in the process.

Patel, Henderson, Bradley, Galloway, and Hunter (1991) conducted another study to investigate the relationship between blink rates and tear stability (this time measured in terms of tear thinning time, TTT, instead of TBUT). Sixteen subjects were tested as they played a computer game in front of a VDT. The study does not mention if the subjects were regular VDT users. The findings show that blink rates decreased from 18.4 blinks/min, during normal conversation (non-VDT task), to 3.6 blink/min, after VDT use. On the other hand, mean tear stability, which was measured at 40.2 sec. before VDT use, and 42.4 sec after VDT use, did not change significantly. Although tear stability was not found to be effected by VDT use, a significant association was found between TTT and blink rate during VDT, with a correlation coefficient of -0.621 . Patel et al. (1991) suggested that the corneal nerves can detect changes in tear stability before TTT, and provide feedback to induce blinking, in order to prevent local thinning and break up in the tear film. The absence of difference in TTT prior to and after VDT use resulting from their study must be viewed as inconclusive due to the fact that tear volume could not be measured during VDT use. Therefore, the study could have possibly failed to discover existing changes. The time of the VDT task, 10 minutes, may also not be long enough to detect changes in tear volume.

The correlation found by Patel et al. (1991) between TTT and blink rate supports earlier findings by Prause and Norn (1987) which conclude that a significant negative correlation between tear TBUT and blink frequency does exist. In their study, Prause and Norn studied 32 subjects with normal TBUT and 29 subjects with abnormal TBUT

(suffering Sjogren's syndrome). The findings in their study indicate that the subjects with high (normal) TBUT blinked significantly less than subjects with low (abnormal) TBUT.

According to Prause and Norm (1987) “blink frequency is adjusted to tear stability to prevent dry spot formation” (p. 21). Moreover, they suggested that the increased blink frequency could be a sign of dry eyes.

Mental Activities and Blinking

Involuntary blinking is thought to be partially controlled by central nervous system (CNS) mechanisms located within the basal ganglia and reticular formation of the brain. This idea explains why blinking is believed to be affected by concentration, emotions, and the degree of difficulty of visual tasks (Patel et al., 1991). In 1927, Ponder and Kennedy conducted several studies in blinking, and concluded that besides its physiological purpose of protecting the eye, blinking "is closely related to mental tension of the subject at the time and that the movement constitute a kind of relief mechanism whereby nervous energy, otherwise not utilized, passes into a highly facilitated path" (p. 110). With this idea in mind, Ponder and Kennedy proposed that blinking might also be used to measure expended human energy in seeing. They suggested that eyelid movements are usually activated and controlled by the CNS rather than by environmental factors such as lighting and particles. These studies were further supported by Meyer, Bahrick, and Fitts (1953), and Meyer (1953), who proposed similar theories (Stern, 1994). In agreement with Ponder and Kennedy, their theories suggested that blinking involves efferent neural interactions between the brain mechanisms, which are responsible for the muscles controlling the eyelids, and other muscle groups.

Other studies have supplied evidence that blinking is not only triggered by CNS activity in the brain, but is also feedback to the CNS when the corneal nerves are stimulated. Holly (1973), Patel et al. (1991), and Prause and Norn (1987) anecdotally suggested that dry spots in the cornea irritate the nerve endings, and therefore trigger involuntary blinks. In addition, as discussed earlier, Collins et al. (1989) also demonstrated that corneal nerves could detect changes in the tear film and trigger blinking.

Task Difficulty

Several studies have shown that blink rates decrease as the degree of difficulty increases (Luckiesh & Moss, 1937; Stern, 1994). As early as 1927, Ponder and Kennedy found that blinking significantly decreased during visual tasks such as reading or visual tracking (Stern, 1994). Therefore, in this study, we can expect blink rates from any of the reading trials to be lower than those from the relaxed gaze trials.

Time-on-task (Fatigue) Effects

In 1935, Luckiesh and Moss investigated the effects time-on-task (TOT) could have on blink rates. In order to do so, they studied subjects reading for 1 hour. Their results show that blink rates increased with time-on-task: 1) blink rate increased from 22.4 blinks/minute prior to reading, to 33.0 blinks/minute 5 minutes after the reading. In another study by Mourant, Lakshmanan, and Chantadisai (1981), blink rates for 6 subjects were compared while reading for 2 hours from a cathode ray tube (CRT). The study found a significant increase in blink rates with time-on-task. The increase was measured to be from 3.73 blinks/minute, during the first half-hour of reading, to 4.95

during the last half-hour of reading, $p < .01$. On the other hand, Miyao, Hacisalihzade, Allen, and Stark (1989) compared blink rates for 10 subjects while the subjects read out loud for 1 hour from both high and low resolution VDTs. Their results illustrate only a meager increase in of 8.6 ± 9.8 blinks/minute during minutes 0- 5, and 11.3 ± 12.8 blinks/minute during minutes 27.5 - 32.5, and 12.7 ± 11.5 blinks/minute during minutes 55 - 60. The contradicting results expressed in previous studies may be due to differences in tasks studied. Luckiesh and Moss' task involved reading from a book, while the Maurant et al. task involved reading from a CRT, and the Miyao et al. task involved reading out loud from a VDT. Time of task effect seem to be mainly sensitive to the type of task performed. According to Luckiesh and Moss (1937):

The rate of blink is increased without exception when the specific task is made more difficult or prolonged. However, this generalization may not extended to include various types of tasks; that is, the reflex blink is not necessary an adequate criterion for comparing tasks that are radically different in character. (p. 224)

It is difficult to determine if time-on-task will contribute to higher blink rates in this study, and therefore, effects attributed to time-on-task are not expected during the reading tasks. A time-on-task period of 5 minutes was selected for this study based on the fact that significant changes in blink rate during reading has been found with periods as short as 3 minutes (Prause & Norn, 1987).

Electrooculography Measurement

Over the past 30 years, techniques used to measure blink rates, and other visual parameters, have experienced an astounding evolution from direct observation, to the use

of video tape, to infrared eye tracking systems, and, finally, to electrooculography (EOG) recording (Morris, 1984). EOG is a method that indirectly records voltage changes in the eye while the eyeball rotates. It is the only eye movement recording technique in which the signal is generated by a bioelectric event in the eye. It measures the bioelectric potential between the positively charged cornea and the negatively charged posterior of the eye. The eye then behaves as a battery originating dc voltage that radiates into adjacent tissue, and creates a potential field that rotates with the eyes (Morris, 1984).

There are several important advantages to EOG. For example, head movements generally do not affect the accuracy of an EOG recording because the signal source is located within the eye. No devices, which could interfere with vision or produce discomfort, need to be attached to the eyes or eye wear.

In conclusion, the frame work followed for this study can be summarized according to the following theories: (a) blink rate decreases during VDT use due to the increase in concentration and visual demands, (b) ocular surface area exposed during VDT use increases with elevated viewing angles, (c) increase in ocular surface area results in faster tear evaporation and therefore less tear volume, (d) interdependency between tear volume and blinking affect the resulting blink rate. The review of previous researches supports the stated theories. This study seeks to investigate how these combined theories apply to changes in viewing angle during VDT. Additionally, time-on-task effects on blink rate and self-reported ratings of visual and musculoskeletal discomfort will be evaluated.

Methods

Subjects

Twenty subjects, 13 males and 7 females, ages 25-57 years old ($M = 39$ years), participated in this research for a period of one hour each. All subjects are employees of the Lawrence Livermore National Laboratory (LLNL), who volunteered their time to participate in this study, and were not paid. All experimental sessions were conducted within the first 4 hours of the subjects' working day. The subjects were screened by an optometrist regarding factors that may affect blink rates such as visual pathologies, medication, and visual acuity. Subjects were selected if they had good near vision, or wore appropriate corrective lenses (single vision, or gradual bifocal lenses), while volunteers with bi-focal (non-gradual) and contact lenses were excluded from the study.

All subjects use VDTs regularly at work for a minimum of 2 hours per day. Subjects were treated according to the Human Subjects Review Board's code of conduct, and were not informed about the blink rate measurements as an effort to prevent biased responses. Instead, they were told that several physiological responses of the eyes were to be measured, and that they would be offered more specific information on the measurements upon completion of the study.

Design

The study was designed as a within-subject experiment (with repeated measures), with the viewing angle and time-on-task as the independent variables. The dependent variable measured was the blink rate (blink/minutes). A total of five levels were used for time-on-task: minutes 1, 2, 3, 4, and 5. Four levels of vertical gaze angles were used: 15

degrees above eye level, zero degrees or eye level, 15 degrees below eye level, 30 degrees below eye level. Subjects were randomly assigned to four treatment groups, which consisted of five subjects each. Within each treatment group, the vertical gaze angles were presented in a counterbalanced order with the purpose of controlling practice effects:

Viewing Angle Presentation					
Trial	1	2	3	4	
Group 1	A	B	D	C	A = + 15 ° above eye level
Group 2	B	C	A	D	B = 0 °, or eye level,
Group 3	C	D	B	A	C = -15 ° below eye level
Group 4	D	A	C	B	D = -30 ° below eye level

A sample size of 20 subjects was calculated with $\alpha = 0.05$, $\beta = .20$, and standardized effect size of 0.89 (based on blink rate results from previous study by Patel (1991) to achieve 80% power (Hulley & Cummings, 1988).

Subjective visual discomfort ratings were measured with a modified Rated Perceived Exertion (RPE) scale created by Borg (Drury, 1992). Subjective musculoskeletal discomfort rating was measured with a modified Body Part Discomfort scale (BPD) adapted from Corlett and Bishop (Drury, 1992).

Instrumentation:

Eye blinking rate was measured by electrooculography (EOG) while subjects read text from a VDT screen. Electrooculogram signals (in mV) were measured through the use of a headband containing five electrodes and placed on the subject's forehead (Figure 1). The signals were processed with the eight channel bioelectrical signal-processing

device, BioMuse, which uses an optically isolated analog-to-digital section to sample subject data, and a digital signal processor to perform preliminary filtering on the data. A laptop computer and Biohost software were used to collect and process EOG signals from the BioMuse. The subject's forehead was first cleaned with an electrode preparation solution to wipe off sweat and debris.

Text from Encarta for Windows 95, World War I history, was used for the reading task. It was displayed to the subject on a color 17 in. VDT screen. The displayed font size was maintained constant throughout trials, for all subjects. The text window was reduced to 3 $\frac{3}{4}$ in x 9 $\frac{3}{4}$ in with the purpose of reducing the amount of vertical eye movement needed to read the text at the desired suspended viewing angle. The text was displayed continuously, allowing the subject to scroll up and down to the next page by simply clicking the mouse. A mouse was the only input device used by subject, no keyboard was required.

A height adjustable bi-level table was used to adjust the VDT and mouse heights, and a height adjustable chair allowed the subjects to sit at the appropriate height from the floor (occasionally, a footrest was also used). A Sony video camera recorded the entire experiment on video.

Environmental conditions such as temperature and airflow were kept constant through a central heating system. Same lighting conditions were used throughout the experiment. A Photo-Meter 1, by Quantum Instruments, was used to measure illumination and luminance at the workstation. Matlab5 software was used to filter the EOG signals. SPSS software program was used to perform the data statistical analysis.

Procedure:

Prior to the experiment, the subjects were screened by an optometrist (Appendix A). During this brief interview, information regarding the subject's desired distance to the monitor was recorded. If the subject wore corrective lenses, their glasses were used when determining this distance. In addition, these subjects were instructed to bring their prescription glasses to the experimental session. The determined distance was then used to calculate the monitor height adjustments in order to achieve the desired suspended viewing angles to the text screen.

The Biomuse was set up as follows: channel 5 was for vertical movement of the left eye, channel 6 for horizontal movement of the left eye, while channel 7 for horizontal movement of the right eye, and channel 8 for vertical movement of the right eye. Gain was set at 100 Hz, while the sampling frequency was set at 250 Hz.

Illumination on the VDT screen was measured at the various screen heights, and measured an average of 3.9 footcandle. Luminance between the subject and screen was measured at the various screen heights, and measured an average of 4.7 footlambert. The subject's forehead was wiped before placing the headband. The headband and Biomuse were tested to ensure proper functioning. Glasses were cleaned if needed, and necessary chair adjustments were made to ensure that each subject was sitting comfortably with their feet planted on the floor, and thighs relatively parallel to the floor. The subject's eye level and elbow height to the floor were then measured and recorded, and the necessary monitor and mouse surface height adjustments were completed (Figure 1).

Required monitor heights for each subject were calculated using the desired suspended angle from the subject's eye level height to the top of the text screen ($3\frac{3}{4}$ in x $9\frac{3}{4}$ in), usually displayed in the top portion of the monitor, and visual distance to the screen. The monitor screen was kept vertically flat, perpendicular to horizontal plane, to minimize glare from overhead lighting.

Subjects were then instructed on how to handle the mouse, and navigate through the text by scrolling one screen at a time, and were then allowed to practice for a couple of minutes. They were also provided the following instructions: (a) to read the text displayed on the screen continuously and at their normal pace until instructed to stop, (b) to keep their eyes on the screen during the entire trial, (c) to try to maintain a good, but comfortable posture, and, finally, (d) to use primarily eye movements to read the text while avoiding large head and body movements. Furthermore, they were asked to read the text entirely, and were told that a brief questionnaire would be administered at the end of each trial. Before the study began, the subjects were asked to gaze at the horizon (long distance), and were instructed to relax for 5 minutes while the program was set up. Eye blink data from this time period was used as a baseline to measure their relaxed gaze blink rates.

Prior to each trial, the video camera was turned on to record eye and head movements. A total of four experimental trials were conducted in this fashion, each lasting 5 minutes. After each trial, the subjects were asked to fill out a questionnaire regarding any visual and musculoskeletal discomfort experienced during the trial (Appendix B). The experimenter occasionally asked the subjects simple questions on the

reading material in order to motivate them to continue reading. The subjects were given two-minute breaks between trials, during which, they were asked to stand up and walk around, but were instructed not to remove the headband.

Figure 1. Experimental set up at various viewing angles: eye level, 15 degrees above, 15 degrees below, and 30 degrees below eye level.

Results

The resulting blink signals were compared to the information recorded on videotapes, and counted the number of blinks per minutes, per trial, for each subject. Blinks caused by coughing, sneezing, outliers, etc. were removed from the data set. Ratings from the questionnaires were also evaluated and analyzed.

Blink Rate

In Table 1, the mean, standard deviation, minimum and maximum statistics for the resulting blink rate of 20 subjects are provided. The mean blink rate is plotted in Figure 2 against vertical viewing angle. In Figure 3, the mean blink rate was plotted against time-on-task across the 5 minutes trials. In Figure 4, the mean blink rate over time-on-task (reading from computer screen) is plotted according to the viewing angle, and is then compared to the blink rate at the relaxed gaze (when subjects just relaxed and gazed into the horizon, and were not reading or looking at a computer).

A two-way ANOVA (viewing angle x time-on-task), with repeated measure across two factors and $\alpha = .05$, was performed to test the following hypotheses: (a) blink rate does not change with variations of viewing angle, (b) blink rate does not change with time-on-task, and (c) there is no interaction between viewing angle and time-on-task effects. The ANOVA results are shown in Table 2. Significant effects on blink rate were found for viewing angles, $F(3, 57) = 3.22$, $p < .05$, and for time-on-task, $F(4, 76) = 17.50$, $p < .05$. No significant effects were found for the interaction of viewing and time-on-task, $F(12, 228) = 0.71$, $p > .05$.

Post hoc analysis was performed using Tukey's HSD (honestly significant difference) test. For the viewing angle main effect blink rate at eye level ($\bar{M} = 7.25$) was significantly higher than at 30 degrees below eye level ($\bar{M} = 5.91$), $t = 2.12$, $HSD = 1.66$. For the time-on-task effect, blink rate was significantly higher in the 4th minute ($\bar{M} = 7.55$) and 5th minute ($\bar{M} = 7.94$), than during the 1st, 2nd, and 3rd minutes ($\bar{M}s = 5.38, 5.78, 6.29$, respectively), $t_s = 3.49, 4.0, 2.85, 3.43, 1.92, 2.5$, respectively, $HSD = 1.74$.

The strength of relationship between viewing angle and blink rate has an eta-squared of 0.40. The strength of relationship between time-on-task and blink rate has an eta-squared of 0.52. These percentages are high considering the number of subjects used in the study. The observed power for the viewing angle effect was 0.72, while for time-on-task effect it was 1.00.

The order of presentation of the viewing angles was counterbalanced to prevent carryover and fatigue effects. A two-way ANOVA (order x vertical gaze angle) confirms there was no significant effects on blink rate due to order, $F(3,9) = 0.45$, $p > 0.05$.

Subjective Rating of Discomfort

Subjective data on eyestrain and muscular discomfort collected from the questionnaires were then analyzed. The mean eyestrain rating from 20 subjects across viewing angles is summarized in Figure 5. The scale ranged from 6 = no strain at all, to 19 = extremely straining (Appendix B). Figure 6 summarizes the mean rating reported for muscular discomfort experienced by subjects during each trial. The scale ranged from 0 = no pain/discomfort, to 3 = intolerable pain/discomfort (Appendix B).

Age

A MANOVA analysis was performed with age as the between subject variable, and (vertical gaze angle x time-on-tasks) as the within subjects variables. Subjects were grouped into two groups. Group 1 consisted of subjects under 45 years of age ($\underline{n} = 14$), while group 2 was formed by subjects age 45 and over ($\underline{n} = 6$). No statistically significant effect was found between age and viewing angle effects, $\underline{F} (3, 54) = 0.305, p > .05$, or between age and time-on-task effects, $F (4, 72) = 1.107, p > .05$.

Table 1

Blink Rate (blinks/minute) Statistics

Condition	M	SD	MIN	MAX
<u>Viewing Angle</u>				
15 ° above eye level	6.72	2.87	1	14
0 ° eye level	7.25	3.38	1	16
15 ° below eye level	6.54	3.05	1	17
30 ° below eye level	5.91	2.85	1	13
<u>Time-on-task</u>				
1 min.	5.38	2.88	1	13
2 min.	5.78	2.51	1	13
3 min.	6.29	2.65	1	13
4 min.	7.55	3.14	1	16
5 min.	7.94	3.34	2	17

Table 2

ANOVA Results (Viewing Angle x Time-on-Task)

Source	DF	MS	F	Fcrit	p-value
Angle	3	30.550	3.221	2.605	.029
Error(Angle)	57	9.485			
Time	4	99.541	17.502	2.372	.000
Error(Time)	76	5.687			
Angle*Time	12	2.823	0.711	1.752	.740
Error(Angle *Time)	228	3.971

Figure 2. Overall mean blink rate for 20 subjects across viewing angles at 15 degrees above eye level (15+), at eye level (0), 15 degrees below eye level (15-), and 30 degrees below eye level (30-).

Figure 3. Overall mean blink rate for 20 subjects across time-on-task from 1 minute to 5 minutes.

Figure 4. Mean blink rate against time-on-task (during computer work) by viewing angle at 15 degrees above eye level (15+), at eye level (0), 15 degrees below eye level (15-), and 30 degrees below eye level (30-), and at relaxed gaze (no computer work).

Figure 5. Mean self-reported eye strain/discomfort rating by viewing angle at 15 degrees above eye level (15+), at eye level (0), 15 degrees below eye level (15-), and 30 degrees below eye level (30-). Rating scale ranges from 6 to 19.

Figure 6. Mean self-reported muscular strain on various body parts at viewing angle 15 degrees above eye level (15+), at eye level (0), 15 degrees below eye level (15-), and 30 degrees below eye level (30-). Rating scale ranges from 0 to 3.

Discussion

The purpose of this study was to determine the effects of vertical viewing angles and time-on-task on blink rate, and the null hypotheses were tested accordingly. Based on the data analyses, the null hypothesis stating that variations in the viewing angle do not affect blink rate can be rejected with reasonable certainty (Table 2). Instead, the data indicated that blink rates decreased significantly as the viewing angle decreased from eye level or zero degrees to 30 degrees below eye level (Figure 2). Although not significantly, blink rates also decreased as the viewing angle increased from eye level to 15 degrees above eye level. The association between viewing angle and blink rate appears to be non-linear. The data statistics reported in Table 1 demonstrate marked variations between individuals' blink rate. Similar findings are reported in most studies involving blink rate (Carney & Hill, 1982; Stern, 1994). Data analysis also shows blink rate decreased significantly from the relaxed gaze condition (non-VDT) to the overall mean blink rate during VDT reading conditions (Figure 4). The fact that blink rates are lower during VDT use than they are during relaxed conditions has been supported in many studies including those of Patel et al. (1991), Sotoyama et al. (1995), and Tsubota and Nakamori (1993). Additionally, this study indicates that blink rates during VDT use increased with elevation of vertical viewing angle.

The increase in blink rate as the viewing angle approaches eye level (and eyes open wider) may not appear to support the theory that increased ocular surface area at elevated VDT heights results in lower blink rates due to the faster tear evaporation rates, as reported by Villanueva et al. (1996), Sotoyama et al. (1995), and Tsubota and

Nakamori (1993). However, when the theory of interdependency between tear thinning time (and break-up time) is considered, the increased blink rate with elevated viewing angles seems to support both theories. Studies by Collins et al. (1989), Patel et al. (1991), and by Prause and Norn (1987) support this interdependency and suggested that corneal nerves detect changes in tear film stability and provide feedback to induce blinking prior to the formation of dry spots. Prause and Norn therefore suggested that increased blink frequency could be a sign of dry eyes. Yaginuma et al. (1990) also demonstrated that faster tear evaporation could result in increased blink rate. Hence, the increase in blink rate with elevated viewing angles during VDT use could be explained as follows: the increased ocular surface area lead to faster tear evaporation and therefore to dry eyes, which in turn caused the eyes to blink more frequently in order to prevent further dryness.

However, the decreased blink rate for viewing angles above eye level does not conform to these theories suggesting that other factors (i.e. biomechanical ones) are also involved. Further research indicates that the ability for the eye to blink when the eyeball is rotated upward is limited. According to Doane (1980):

In most instances, there is no rotation of the globe during the blink, unless the eyelid is restrained of the blink is strong or forced.... Although the globe does not normally rotate upward during blinking, it does move in a posterior-anterior direction. This implies that there is considerable pressure exerted on the anterior surface of the globe by the descending upper eyelid. (p. 513)

It appears that the eyelid blinking mechanism becomes destabilized when the eye is rotated upwards, inhibiting, and therefore, reducing blink rate. Villanueva et al. (1996) made a similar observation when they found that the subjects' vertical gaze angle seemed limited when viewing screens at taller heights, compared to angles at the lower heights.

It is interesting to note that the blink rate at eye level during the VDT reading tasks was the closest to the blink rate measured during the relaxed gaze (non-VDT task). This is to be expected since the viewing angles are almost equal, and therefore, the exposed OSAs are also almost equal. Similarly, when comparing the OSA exposed while using a VDT, during relaxed conditions, and while reading a book, Tsubota and Nakamori (1993) found the OSA during relaxed conditions and the OSA during use of a VDT to be the closest. The blink rate during the relaxed gaze condition could be considered as the subject's natural blink rate in which normal tear stability can be maintained (Carney & Hill, 1982).

Based on the preceding discussion elevated viewing angles, at eye level and 15 degrees above eye level are more likely to be associated with dry eyes than the lower viewing angles of 15 and 30 degrees below eye level. But recommendations for viewing angles during VDT use can not be made based on eye blink rate alone. Other factors such as time-on-task, and postures must also be considered.

Further data analyses indicate that the hypothesis stating that blink rates do not change with time-on-task can be rejected with reasonable certainty (Figure 3). On the other hand, the hypothesis stating that there is no interaction between viewing angle and time-on-task effects can not be rejected. Blink rate increased continuously with time-on-

task during a 5-minute period. Eye blink rate was significantly higher in the 4th minute and 5th minute, than during the 1st, 2nd, and 3rd minutes. The results imply that as subjects spent more time reading, blink rates increased as a function of time-on-task. The results support previous studies by Luckiesh and Moss (1935) and Mourant et al. (1981). But they also contradict results by Miyao et al. (1989), which did not find significant effects for time-on-task. Because time-on-task effects are believed to be highly sensitive to the nature of the task (Luckiesh & Moss, 1937), the differences in results may be attributed to the different nature of the tasks performed in the studies. The fact that the blink rate continued to increase until the last 5 minutes indicates that blink rate had not yet stabilized in 5 minutes, which suggests that periods longer than 5 minutes may need to be investigated. Increased blink rate with time-on-task could also be associated with increased dryness of the eyes. Further understanding in this area could be helpful in determining a frequency for computer breaks in order to reduce eye dryness.

Analyses of the subjective ratings for eye strain (Figure 5) shows that the highest eye strain rating was reported for the viewing gaze of 15 degrees above eye level (15+), which was categorized as somewhat straining. This was followed by the viewing angle of 30 degrees below eye level, categorized as causing little strain, and then by eye level (0 degrees) and 15 degrees below eye level, both categorized as causing very little strain. Analyses of the subjective rating for muscular discomfort (Figure 6) shows the highest rating of discomfort was reported in the neck area at the 15 degrees above eye level (15+), and was classified as moderate. The next level of discomfort was reported in the neck area at the 30 degrees below eye level (30-), classified as noticeable. This was

followed by the lowest ratings of discomfort in the neck, shoulders, and lower back, which were reported at the eye level condition (0 degrees), and were classified as noticeable. These results suggest the use of viewing angles between eye level and 15 degrees below eye level are best capable of minimizing visual and musculoskeletal discomfort. At the same time, viewing angles above eye level and 30 or more degrees below eye level should be avoided.

Post analyses on blink rate during VDT use and the subjects' age did not show a difference in results between subjects less than 45 years of age and those 45 and over. The age of 45 was selected as a cut-off point based on reports that focussing power decreases significantly at ages 45 and over (Shurts & Bommarito, 1996). The lack of significance in differences in blink rates between the two age groups supports findings by Sun, Baker, Chuke, Rouholiman, Hasan, Gaza, Stava, & Porter (1997).

Combined blink rates and self-reported ratings of discomfort from this study suggest that the use of viewing angles near 15 degrees below eye level optimize blink rate, reduce potential eye dryness during VDT work, and provide a comfortable posture. Although postures with VDT at eye level appear to be the least straining on the musculoskeletal system (Hamilton, 1996; Villanueva et al., 1997), the increased blink rate during this viewing angle indicates that eyes could dry faster at this level. Furthermore, many researchers have reported improved physiological performance of accommodation and dark vergence, among other factors, when near visual work is performed at a downward vertical gaze (Leavitt, 1995; Sotoyama et al., 1995; Villanueva et al. 1996). Hence, a vertical gaze angle range close to 15 degrees below eye level

would be recommendable. This recommendation is congruent with the range of 10 to 20 degrees recommended by the American Optometric Association (1994).

Hence, the specific information learned from this study about blink rate and viewing angle during VDT can be used to support previous recommendations by other researchers for viewing angles close to 15 degrees below eye level since they minimize neck deviations while providing visual comfort. Furthermore, this information can be useful to generate more specific design guidelines for products related to computer workstations, including VDTs, furniture, eyewear and visually activated devices (American Optometric Association, 1994; Sotoyama et al., 1995; and Villanueva et al., 1996). For example, the 1988 American National Standard Institute technical standard, ANSI/HFS-100, for VDT workstation design has the following guideline with respect to viewing angle "The height of the display support surface shall permit the entire primary viewing area of the display screen to be located between 0 degrees and 60 degrees below the horizontal plane passing through the eyes." (p. 49). Similarly, the 1989 Canadian Standards Association's Guideline on Office Ergonomics, CAN/CSA-Z412-M89, recommends to place the top of the screen approximately at the operator's eye level when the head is held up. Furthermore, they recommend a lower limit for viewing angle of 45 degrees below eye level. Again, the results in this study suggests that a narrower range of viewing angles, near 15 degrees below eye level, would be preferable from a visual and musculoskeletal perspective. If a wider range is required due to larger screen sizes, then a maximum range between eye level and 30 degrees below can be considered, with a potential increase in discomfort. The incorporation and proliferation of specifications on

viewing angles is in great need as VDT screen designs continue to change. For example, the increased demand for multiple Windows display is driving the need for larger screens, and making it more difficult to place screens below eye level. Therefore, the use of larger screens may induce an upward gaze, which is likely to lead to visual and neck strain. Hence, in the design of equipment to be used for visual intensive tasks, paying attention to the impact it may have on the visual system can help prevent or reduce user discomfort.

Limitations

The findings of this study are limited by several factors. First, the 5 minutes time-on-task investigated appears to be short since the blink rates were still climbing at the end of the 5 minutes. Additional research needs to be conducted to better understand time-on-task effects on blink rate during prolonged periods of VDT use, and also with variations of computer tasks. A time period of at least 2 hours is suggested based on reports by Iwasaki et al. (1985) that decreased level of tear volume and TBUT occur approximately after 2 hours of computer work (Yaginuma et al., 1990).

Second, the results in this study are based on subjects with good vision, or with appropriate corrective lenses. Only single vision lenses or progressive bifocal lenses were used by subjects. Hence the experimental condition in this study may produce different effects on people that have visual pathologies, or who wear different types of lenses such as contact and bifocal lenses.

Third, potential differences in blink rate due to gender were not investigated in this study. In general, blink rate between male and females can be expected to be equal.

However, it is possible that physiological changes in women's tear volume during periods of significant hormonal changes, such as pregnancy and menopause, may also affect their blink rate (per discussion with Paul Bommarito, O.D. on April 2, 1998). Such effects were not taken in consideration in this study.

Conclusion

The main purpose of this study was to determine if eye blink rate changes with changes in VDT viewing angles. Previous studies indicated a decrease in blink rate during VDT use, but whether blink the rate changed at different VDT viewing angles was not known. The results show that blink rate does change with viewing angles, and that the highest blink rates are maintained at viewing angles between eye level and 15 degrees below. The increased blink rate at elevated viewing angle are congruent with the theories of increased tear evaporation due to larger ocular surface area exposed, and of interdependency between tear volume and blink rate. Combined blink rates and self-reported ratings of discomfort from this study further suggest that the use of viewing angles near 15 degrees below eye level could optimize blink rate, and reduce potential discomfort during VDT work.

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Appendix A. Subject Information Sheet

Name:
 Phone Number:
 Gender: Male / Female
 Age:

Subject Code #:
 Scheduled Date/Time:

- 1) Do you currently use a personal computer on a regular basis at work or home?
 (Yes/ No)
- 2) How many hours per day (average) do you normally work on the computer?
 _____ hours/ day
- 3) What is the approximate (horizontal) distance between you and the computer display
 you normally work at?
 _____ cm.
- 4) Do you experience any type of visual discomfort when you work on the computer?
 Please describe discomfort(s).

5) Do you wear eye corrective lenses? (Yes/ No)

6) Type of corrective lenses you wear?

_____ contact lenses	_____ tri-focal lenses
_____ single focus lenses	_____ progressive power lenses
_____ bi-focal lenses	_____ others

Date of last prescription: _____

7) Do you suffer from any type of eye disorder, excluding refractive errors (i.e. near sightedness, far sightedness, stigmatism) ? Please describe.

Inflammations and Irritations _____

Eye muscles balance problems _____

Dry eyes _____

Allergies related problems _____

Other eye diseases (e.g. Conjunctivitis) _____

8) Do you suffer from any type of muscular-skeletal disorder in the back, neck, or upper extremities? Please describe.

9) Do you take any medication regularly? Please list medication(s).

Eye Medication

Prescriptive

Over the counter

Other Medication

Prescriptive

Over the counter

10) Which shift of day do you normally work? Please circle.

Day / Swing / Grave / Other:_____.

Appendix B. Strain/Discomfort Rating Questionnaire

Subject Code #:

Trial: 1 2 3 4

1) Please rate the amount of eye strain/discomfort, if any, felt during the trial you just completed by circling the appropriate number below.

<u>Rating</u>	<u>Interpretation of rating</u>
6	No strain at all
7	
8	Extremely little strain
9	Very little strain
10	
11	Little strain
12	
13	Somewhat straining
14	
15	Straining
16	
17	Very straining
18	
19	Extremely straining

2) Please rate the amount of muscular strain/discomfort, if any, felt during the experimental trial you just completed by selecting the appropriate number on the scales provided below.

Neck 0 1 2 3

|-----|-----|-----|-----|

No Just noticeable Moderate Intolerable

pain/discomfort pain/discomfort pain/discomfort pain/discomfort

Shoulder 0 1 2 3

|-----|-----|-----|-----|

No Just noticeable Moderate Intolerable

pain/discomfort pain/discomfort pain/discomfort pain/discomfort

Upper 0 1 2 3

Back |-----|-----|-----|-----|

No Just noticeable Moderate Intolerable

pain/discomfort pain/discomfort pain/discomfort pain/discomfort

Lower 0 1 2 3

Back |-----|-----|-----|-----|

No Just noticeable Moderate Intolerable

pain/discomfort pain/discomfort pain/discomfort pain/discomfort

IMAGE EVALUATION TEST TARGET (QA-3)

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