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Effects of Computer Display Design on Health and Productivity

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by

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Abstract

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Long hours of computer work in the modern workplace are associated with visual and musculoskeletal symptoms and disorders, which are recognized by the World Health Organization as major occupational health concerns. The rising age of the workforce imposes new challenges in office ergonomics due to the changes in vision and musculoskeletal characteristics of these computer users.

To investigate the effects and mechanisms of oculomotor demands on the most common complaints associated with prolonged computer use, blurred vision, eyestrain, and irritation of the eyes, a within-subject design laboratory study with 17 young subjects was conducted. Subjective ratings of symptoms and objective static and dynamic accommodation and convergence responses were recorded during and after a 2-hour visually demanding computer task. Each subject repeated the task over 6 days using different combinations of natural and optically-modified oculomotor demands. While there was little effect of viewing distance on symptoms, an elevated static accommodation response and a reduced dynamic divergence response were found for the natural near viewing distance condition (33 cm) compared to the far viewing distance (100 cm). Optical manipulation had no effect at the far viewing distance (100 cm), whereas artificially decreasing the accommodation demand at the near viewing distance increased eyestrain. Divergence limits was identified as a factor for predicting the symptom of eyestrain.

A second within-subject, full-factorial design laboratory study with 19 young and 7 older, presbyopic subjects investigated the effects of age, font size, and reflective glare on productivity, upper body posture, and visual and upper body discomfort, in a setting where the subjects could freely adjust their posture and chair position while performing visually demanding tasks on a computer. Compared to the larger font size, the smaller fonts had significant negative effects on all outcome measures: productivity (speed and accuracy) was lower, visual and neck symptoms were higher, and viewing distance was decreased. The reduced viewing distance was primarily due to forward torso flexion (78%), followed by moving the chair forward (4%) and forward head movement (3%). Screen glare induced non-neutral upper body postures, including neck flexion, torso forward flexion, and head movement to the side. There was little effect of age and presbyopia on the study findings.

In summary, the first study demonstrated no difference in visual symptoms when viewing a computer monitor for 2 hours at 33 vs. 100 cm distance. However, there was some evidence of persistent oculomotor effects at the 33 cm distance. The second study demonstrated the benefits of a larger font size and eliminating screen glare on productivity, upper body postures, and symptoms when performing visually intensive

tasks. The benefits were similarly experienced by both the younger and older computer users. The non-neutral, forward leaning postures, observed in many computer users, are likely due to font sizes that are small relative to visual acuity.

To my dearest husband (and best friend forever), who loves, understands, and believes in me deeply, and always brings sweetness, warmth, and joy to my heart!

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Chapter 1

Introduction

Scope of the Problem

According to a 2003 US Census Bureau's Current Population Survey (CPS) data, 56% adults used a computer at work (Day, Janus, Alex, & Davis, Jessica, 2005). Extended hours of stationary computer work in the modern workplace have led to visual symptoms as well as musculoskeletal symptoms and disorders, which are recognized by the World Health Organization (WHO) as major occupational health concerns (World Health Organization, 1987). Approximately 75% of optometric patients who use a computer regularly for 2 hours or more a day are likely to be symptomatic (Salibello & Nilsen, 1995). Computer vision syndrome was recently defined by the American Optometric Association as "that complex of eye and vision problems related to near work that are experienced during or related to computer use." The complex of visual symptoms can be categorized into two groups based on the underlying physiological causes (Sheedy, Hayes, & Engle, 2003); irritation and burning sensation are likely to be related to ocular surface's dryness, whereas excess demands on the oculomotor systems of accommodation (eye's ability to focus) and vergence (the eye's ability to use movements in opposite directions to fixate on the single point in space) may cause nonspecific symptoms, such as blur, strain, ache, and headache. Blurred vision and eyestrain are the most common complaints associated with prolonged computer use. Studies have investigated the internal and external factors affecting this group of symptoms, such as characteristics of an individual's oculomotor system and viewing distance and font size, all of which typically determine accommodation and vergence demands on the viewer (Jaschinski, Heuer, & Kylian, 1999; Jaschinski-Kruza, 1991; Rempel, Willms, Anshel, Jaschinski, & Sheedy, 2007; Tyrrell & Leibowitz, 1990).

An elevated incidence of neck/shoulder musculoskeletal symptoms has been reported by computer users across a wide range of occupations (Eltayeb, Staal, Hassan, Awad, & de Bie, 2008; Gerr et al., 2002; Klussmann, Gebhardt, Liebers, & Rieger, 2008; Tornqvist, Hagberg, Hagman, Risberg, & Toomingas, 2009). Sustained non-neutral head and shoulder postures have been identified as important risk factors for neck/shoulder musculoskeletal symptoms (Fernandez-de-las-Penas, Alonso-Blanco, Cuadrado, Gerwin, & Pareja, 2006; Hagg & Suurkula, 1991; Treaster, Marras, Burr, Sheedy, & Hart, 2006). Leaning forward through neck and/or torso flexion increases the biomechanical load of the upper trapezius and the posterior cervical and suboccipital muscles, such as the levator scapulae, all of which are important for postural function for office work (Bennett, 2007). Forwarded head posture increases the cervical muscle load and muscle fatigue. If the non-neutral posture is maintained, sustained muscle contraction may reduce the local oxygen supply, lead to the sensitization of pain receptors, and ultimately cause neck/shoulder pain (Treaster et al., 2006).

Risk Factors

Several vision related risk factors may be associated with visual and musculoskeletal symptoms resulting from computer use: the characteristics of visual function (e.g., reduced ability to converge/diverge or to adjust focus) and visual demands (e.g., suboptimal viewing distance, optical correction, size of the texts, or lighting environment). Studying the effects of these factors in a well-controlled laboratory setting can assess the potential impact of each factor on productivity and symptoms and can provide guidelines for the setup of computers to improve productivity and comfort.

Visual Demands

Oculomotor demands, such as accommodation and vergence, are influenced by the viewing distance and can be modified by lenses and prisms. Viewing comfort is high when the accommodation and vergence demands are proportional, as specified by viewing distance. However, our visual system can tolerate some deviation from the perfect setup. Clinically, the zone of clear and single binocular vision is defined by the boundary ranges of accommodation and vergence of each individual over with which they have clear single vision (Shibata, Kim, Hoffman, & Banks, 2011). This concept has been applied to explain visual symptoms associated with viewing 3D image displays on a computer monitor and it was demonstrated that reducing the conflict between accommodation and vergence demands increased viewing comfort (Hoffman, Girshick, Akeley, & Banks, 2008; Shibata et al., 2011). Because higher oculomotor demands at near viewing distance have been thought to cause visual symptoms after prolonged computer use, we explored the possibility of using visual aids to reduce visual demands in the first experiment presented in Chapter 2. By quantifying the effects of oculomotor demands and an individual's binocular function on the development and persistence of symptoms as well as the objectively measured visual function changes, we hoped to provide information for determining optimal combination of viewing distance and computer-viewing glasses suitable for young computer users.

Presbyopia

In addition to computer and workstation settings, compromised visual function due to aging may affect an individual's visual performance, symptoms, and postures. Presbyopia results from the enlargement and the stiffening of the lens of the eye with age, which leads to an inability to adjust focus, i.e. to accommodate (Fisher, 1973; Glasser & Campbell, 1998; Schachar, 2006). Presbyopia is present in almost all people over 40 years old. Most people over 48 can focus to see clearly only on distances beyond 40 cm and completely lose the ability to accommodate after the age of 55 (Sun, Stark, Nguyen, Wong, Lakshminarayanan & Mueller, 1988). In such cases, a proper visual aid is required for near work. The amount of visual correction needed also depends on an individual's preexisting refractive error. Even with visual correction, the range of in focus viewing distance is limited and this may limit posture variability and prevent older users from getting close enough to the screen when the font size is small. To complicate this further, wearing bifocal or progressive addition lenses restricts the in focus visual field which may lead to increased head extension and increased neck symptoms. These issues are explored in the full-factorial, repeated measures study presented in Chapters 3 and 4, where the productivity, viewing distance, postures, and the visual and physical symptoms of young and older presbyopic subjects were compared. The study also investigates the potential interaction between font size and glare.

Font Size

Font size has a logarithmic relationship with reading speed. Therefore, for computer users working a fixed viewing distances from the monitor, font size can effect productivity (Lee, Shieh, Jeng, & Shen, 2008; Legge & Bigelow, 2011; Legge, Pelli, Rubin, & Schleske, 1985; Levi, 2008; Levi & Carney, 2009; Whitney & Levi, 2011; Whittaker & Lovie-Kitchin, 1993). Most of these studies are performed at fixed viewing distances. It is unclear for natural conditions, where users can freely adjust their chair and viewing distance, how this relationship influences posture. When posture is not constrained, does a user adopt a viewing distance that optimizes performance?

Visual angle of font (VAF) can be expressed as the ratio of the font height to viewing distance. The recommended range of VAF, for normally sighted observers, is mostly between 16 and 22 arcmin (Eastman Kodak Company, 2004; International Organization for Standardization, 1992, 2011; Sanders & McCormick, 1993).

It has been suggested that, without increasing the default out-of-box font size on most computers, the VAF is small and approaches the visual acuity reserve (VAR), which is the ratio of the VAF of the visual target (a letter) to that of a letter at the visual acuity (VA) threshold. This small font size may induce forward head posture and thoracic spine flexion and lead to neck/shoulder symptoms (Rempel et al., 2007). Viewing distance and viewing angle (vertical or lateral) are common variables reported as predictors for symptoms in office ergonomic studies. They can be modified by changing the chair and monitor locations. Because computer users typically do not change font size they have to reduce the viewing distance when the font size is too small. Viewing distance can be reduced by leaning forward (thoracic flexion), moving the head forward, or moving the seat forward. The first two may lead to musculoskeletal discomfort while the latter will not. Therefore, it is important to determine, under natural conditions, whether posture change is a more common approach to changing viewing distances as compared to seating position adjustments. The findings on the effects of font size on productivity, viewing distance, postures, and visual and physical symptoms of young and older presbyopic subjects are reported in Chapters 3 and 4.

Reflective Glare

Daum, Clore, Simms, Vesely, Wilczek, Spittle & Good (2004) demonstrated that even minor vision issues, such as modest amounts of blur, could result in lower performance. In the workplace, other environmental factors, such as reflections on a computer screen from light sources in the office (e.g., windows or overhead lights) may also compromise visual performance and thus job performance. Reflective glare resulting from nearby light sources reflecting off the monitor is one of the most frequent complaints related to computer use (Bernecker, Davis, Webster, & Webster, 1993; North, 1991). However, the effect of reflective glare on productivity has not been well quantified. Reflective glare can reduce image contrast and, if the glare is strong or localized, it may reduce visual acuity or induce discomfort (Sheedy, Smith, & Hayes, 2005). Bailey and Bullimore (1991) reported that older subjects have lower visual performance (i.e., lower visual acuity) and may, therefore, be more susceptible to disability glare than younger subjects. Older people may have lower productivity on a computer task when viewing a screen with uneven luminance as a result of reflective glare, but this theory has not been tested. The eye-screen-light geometry determines the location of the glare on the computer monitor. When it is not easy to change the location of the light source or the monitor to eliminate glare a user may change their postures to try to reduce glare. The effect of reflective glare on productivity, viewing distance, postures, and the visual and physical symptoms of young and older presbyopic subjects are reported in Chapters 3 and 4.

Chapters

This dissertation describes two studies that examine how different variables affect visual and physical symptoms during computer work. Chapter 2 focuses on how binocular vision function and accommodation and vergence demands affects visual symptoms after two hours of performing a visually demanding task on a computer. Chapters 3 and 4 focus on examining the effects of individual (presbyopia) and environmental (font size, glare) factors on the visual and musculoskeletal symptoms, productivity, and postures of computer users.

High accommodative and fixation demands at near viewing distance may be one of the causes of visual symptoms such as blurred vision and eyestrain. In Chapter 2, we investigated the effects of modifying accommodation and vergence demands on visual symptoms during 2 hours of text viewing on a computer monitor set closer (33 cm) and further (100 cm) from the eyes than common usage (~50 cm; Shieh & Lee, 2007). This was a laboratory, within-subject design study (n = 17, 18-35-year-olds) where subjective ratings of blurred vision, eyestrain, and eye irritation symptoms and objective static and dynamic accommodation and convergence responses under six combinations of natural and optically modified oculomotor demands were reported. While near viewing was not associated with increased symptoms it caused temporary over-accommodation and reduced divergence facility. Eyestrain was affected by the addition of lenses at the near viewing distance. This chapter may be submitted to the journal *Optometry* for peer review.

Chapter 3 summarizes the first part of study two and examined the effects of presbyopia, font size, and reflective glare on performance. This was a within-subject, full-factorial design laboratory study (n = 26; 17 young, 18-35-year-olds, and 7 older/presbyopic, 55-65-year-olds) investigating the effects of presbyopia, on-screen font size, and reflective glare on productivity, visual/physical discomfort, and postures of computer monitor users under a realistic situation where the subjects could freely adjust their posture and the chair. Chapter 3 reports on the effects of font size on productivity, viewing distance, visual angle of font (VAF), and visual acuity reserve (VAR). Significant effects of font size on these variables were found, and the potential impact of the study on an ISO standard is discussed. This chapter will be submitted to the journal *Human Factors* for peer review.

Chapter 4 summarizes the second part of study two and investigated the effects of presbyopia, font size, and reflective glare on visual and upper body musculoskeletal symptoms; head, neck, torso posture angles; and the behavioral pattern of adjusting posture. Significant effects of all three factors were found, offering insights into behaviors during computer work and practical implications for workplace recommendations of font size and posture awareness that could prevent symptoms associated with computer work. This chapter will be submitted to the journal *Human Factors* for peer review.

Chapter 5 is a summary of all study findings and recommendations for future laboratory and field studies.

Chapter 2

Visual Symptoms, Accommodation, and Binocular Vision Changes Associated with Computer Use

Abstract

Objectives: Visual symptoms such as blurred vision, eyestrain, and irritation have been associated with prolonged viewing of computer monitors. High accommodative and fixation demands at near viewing distance may be one of the causes for visual symptoms such as blurred vision and eyestrain. We investigated the effects of modifying accommodation (the eye's ability to focus) and vergence (the eye's ability to use movements in opposite directions to fixation on a single point in space) demands on visual symptoms after a 2-hour text viewing task on a computer monitor set at a close (33 cm) or far (100 cm) location from the eyes relative to common usage (~50 cm; Shieh & Lee, 2007).
Method: Seventeen 18–35 year-old subjects with normal vision and binocular vision functions participated in the study. A text-based visually demanding task was performed over a 2-hour period under 6 different viewing conditions. The conditions differed in viewing distance and lens/prism combinations. The conditions were each evaluated on a different day and the order of testing was randomized. In the natural viewing conditions, e.g., no lens or prism, the monitor was placed at either 33 cm or 100 cm from the eyes. In the unnatural, demand-modifing viewing conditions, we applied +1 diopter (D) lenses or 6 prism diopter base-in (PD BI) prisms (symmetrical 3PD BI prism for each eye) to reduce the demands at 33 cm; we also increased the binocular accommodative demand by introducing - 1 D lenses or increased the convergence demand with 6 prism diopter base-out (PD BO) prisms while viewing at 100 cm. The outcome measures included subjective symptom ratings (blurred vision, eyestrain, irritation/tearing) and near point of convergence (*NPC*) as well as objective PowerRef II measures: static accommodation responses (*DistLag*) at 4 meters, dynamic monocular accommodation response amplitude when using a ± 2 D lens flipper (*AMD*), and dynamic divergence response amplitude when using 6 PD BI prism changes (*VBD*). The measurements were obtained before the task and at 0, 30, 60, and 90 minutes after the task to obtain pre- and post-task differences and a measure of retention of change of outcome measures after the tasks.
Results: The symptom changes were similar for natural viewing at 33 and 100 cm. However, objective measures immediately after the 2-hour task were different. At the end of the 33 cm viewing condition, over-accommodation while looking at a distant target (4 m) was 0.17 D larger ($p = 0.038$) and the dynamic divergence response amplitude was 0.92 PD smaller ($p = 0.030$) compared to the 100 cm condition. These differences did not persist during the tests at 30, 60 and 90 minutes after the task. Under unnatural, demand-modifing viewing conditions, a decrease in 1 D accommodative demand at 33 cm produced a greater post-task increase ($p = 0.014$) and retention ($p = 0.0005$) of eyestrain compared to either the natural viewing at 33 cm or the decrease in 6 PD convergence demand at 33 cm. At 100 cm, manipulating the accommodative demand had no effects on symptoms. A separate finding was that a subject's divergence limits had a small but significant effect on eyestrain ($p = 0.001$).

Conclusions: Overall, the level of symptom increase after the 2-hour task was small, and the associations between the objective measures and the symptoms were weak. The direction and the type of the effects were mildly influenced by viewing distance and the induced demand. While there were no differences in symptoms between the natural 33 and 100 cm viewing conditions, a mildly elevated static accommodation response and a reduced dynamic divergence response were observed at the end of the task for the 33 cm viewing condition compared to the 100 cm condition. However, these responses were short lived and did not persist into the follow-up period. Optical manipulations had no effect at the 100 cm distance, whereas changing the accommodation demand, at the 33 cm distance, increased eyestrain but had no effect on the objective measures.

Introduction

Anshel (2005) summarized the prevalence of computer-related eye symptoms by mentioning a Harris poll which concluded that computer-induced eyestrain was the number one office health complaint in 1991; the National Institute for Occupational Safety and Health (NIOSH) also estimated that nearly 60 million people who work at computers over 3 hours a day were suffering from eyestrain in the same year. Additionally, computer vision syndrome is more common than musculoskeletal problems (Anshel, 2005). Visual symptoms such as blurred vision or eyestrain are the most common complaints associated with prolonged computer use. Approximately 75% of optometric patients who use a computer regularly (2 hours or more a day) are likely to be symptomatic (Salibello & Nilsen, 1995). Furthermore, small uncorrected refractive errors may lead to reduced productivity among office workers even when symptoms are unreported (Daum et al., 2004). Computer vision syndrome (CVS) was recently defined by the American Optometric Association as "that complex of eye and vision problems related to near work that are experienced during or related to computer use." The complex of symptoms could be categorized into two groups based on the following underlying physiological causes (Sheedy et al., 2003): dryness and burning sensation were thought to be ocular surface related, whereas excess demands on the oculomotor systems of accommodation and vergence may cause nonspecific visual symptoms, such as eyestrain, ache, and headache.

Some investigations for the internal and external factors affect this group of symptoms; characteristics of an individual's oculomotor system could make one respond differently to the same absolute demands, e.g., specified by viewing distance and font size, which typically determine the focus and fixation demands on the viewer. Longer viewing distances (e.g., 70 cm–100 cm vs. 50 cm) were preferred if the visual angle of the character size was held constant (Salibello & Nilsen, 1995). However, if the character size was not changed (and therefore visual angle size reduces with increased viewing distance), closer viewing distances (e.g., 50 cm vs. 70-100 cm) reduce symptoms and improve convergence recovery (Rempel et al., 2007). Some research associated objective measurements on the oculomotor functions with the occurrence of visual symptoms. For instance, since individuals adapt their vergence to the viewing distance, it is suggested that we bring the task close to the resting state of vergence (i.e. dark vergence, eye posture measured in a dark visual field to eliminate stimuli that can trigger accommodation and vergence response) to reduce visual symptom development, especially if the viewing distance is shorter than the dark vergence position (Jaschinski et al., 1999; Jaschinski-Kruza, 1991; Tyrrell & Leibowitz, 1990). Another example is that individuals with a larger vergence error (fixation disparity) at near viewing distance tend to prefer longer viewing distance (Jaschinski, 2002). The implications of these findings for the workstation design have been discussed, however, their implications for visual aids has not been well explored.

Accommodation and vergence demands can be determined by the viewing distance and then modified by lenses and prisms, respectively. In natural viewing situations without optical modification, accommodation and vergence demand are proportional: vergence demand (in units of prism diopter, PD) is equal to the accommodation demand (in diopter (D), the inverse of viewing distance in meters) multiplied by the viewer's interpupillary distance (IPD, in centimeters). The larger the convergence, the greater the strain on the muscles controlling vergence (Collins, O'Meara, & Scott, 1975). The decoupling, or conflict, between accommodation and vergence demands refers to the deviation of accommodation or vergence demand from the diagonal line (a constant ratio). Adding lenses or prisms can introduce the similar effect of the decoupling normal ratio of accommodation and vergence demand, respectively (Shibata et al., 2011). Nevertheless, the visual system may adapt itself to reduce the discrepancy (Schor & Tsuetaki, 1987).

Clinically, the zone of clear and single binocular vision (ZCSBV, Figure 1) is defined on the convergence-accommodation plot as the region formed by the monocular amplitude of accommodation, zero accommodation, convergence and divergence limits lines estimated by the blur points to base-in (BI), and base-out (BO) prisms at near and distance (Shibata et al., 2011). The binocular visual system can only see clearly and singly for combinations of convergence and accommodation stimuli that are within this area. The zone can differ substantially between individuals. This concept has been used to explain the visual symptoms associated with viewing 3D images on computer monitors: using optical manipulation, such as introducing image blur or alternating image-forming distance, to reduce the conflict between accommodation and vergence demands (i.e. making them proportional as viewing a real object in the world) was shown to reduce viewing discomfort for 3D displays (Hoffman et al., 2008; Shibata et al., 2011).

Several areas require more research and clarification. For example, the zone may also shift after a visually demanding task if the boundaries mark out the zone, which includes maximum accommodation, zero accommodation, and/or convergence/divergence limits, are changed. The boundaries may change due to the adaptive nature of the visual system to sustained visual tasks (Gur, Ron, & Heicklen-Klein, 1994; Schor & Horner, 1989; Tyrrell & Leibowitz, 1990). This adaptive nature may allow the visual system to better meet the demands for performing the visual tasks, or it may be a fatigue response to a constant demand (Hasebe, Graf, & Schor, 2001). In addition, even though the ZCSBV may be able to serve as a basis for predicting the visual system's response to manipulations of accommodation and convergence demands during computer use, some dynamic properties that are relevant to the common visual symptoms, such as the endurance and flexibility of the oculomotor system, cannot be addressed directly by the ZCSBV.

This study attempted to answer the following questions: How do various combinations of accommodative and vergence demands specified by the viewing distance and optical modifications affect the changes of the visual symptoms and the static and dynamic accommodative and vergence responses of computer users with normal and robust vision? How do these effects change right after a 2-hour visually demanding task and are they retained through the next 1.5 hours? By quantifying these effects, we hoped to provide information for determining optimal combination of viewing distance and computer-viewing glasses for young individuals.

Method

Subjects

Seventeen subjects met the inclusion criteria and participated in this repeated measures laboratory study. The inclusion criteria were as follows: 1) being 18 to 35 years of age; 2) being an experienced computer user; 3) having no chronic visual complications; 4) having 20/20 or better visual acuity at a distance (with or without glasses, and a refractive error smaller than 4D); 5) having normal stereo acuity (50 seconds of arc); 6) having normal accommodation amplitude; 7) having normal exophoria (0-4 exo) at near distance; 8) having a normal vergence range; and 9) having normal accommodation facility (monocular: about 12 cycles per minute (cpm); binocular: about 8 cpm). Only half of the potential participants screened met the inclusion criteria. The protocol was approved by the UC Berkeley Center for Protection of Human Subjects, and each subject signed the informed consent form.

Experimental Design

Procedure. The subjects were introduced to the outcome measurements of the experiments without specific information regarding the test conditions. Each testing day's 4.5-hour visit consisted of one set of baseline measurements, 2 hours of a visually demanding task, one post-task measurement set, and three repeats of the outcome measures at 25-minute intervals where changes between these repeated measures defined a recovery measure.

Task. The visually demanding task was a visual search task, similar to common document-editing tasks, involving the use of a mouse (Rempel et al. 2007). A paragraph of random characters consisting of 16 lines of texts at 30 characters per line (Figure 2) was displayed in the center of the computer screen. Each word was between 1 and 10 characters separated by a space. The font size was adjusted to correspond to about 10 arcmin on the retina. The subject had to left click on the space between each pair of words that had the same character on both sides of the space, reminiscent of common document-editing tasks. After finishing a page, the subject right clicked to continue and a page showing the number of mistakes appeared for one second before moving on the next page. These results can be compared to those of previous studies in the literature because this study involved a similar task.

Conditions. There were six conditions in total. The order of the conditions was randomized. Two visual display distances, defined by the distances from the center of the visual display to the subject's eyes (assuming 6 cm IPD), were used: 33 cm and 100 cm, corresponding to 1 D and 3 D accommodation demand and 6 PD and 18 PD vergence demand, respectively (Figure 3A). Six conditions included two natural accommodation and convergence levels at different viewing distances and four conditions with conflict demands achieved by adding lenses to increase or decrease the accommodation demand or prisms to increase or decrease the vergence demand (Figure 3B).

Workstation

The subjects sat in an adjustable chair with their head positions stabilized by a brow bar and a chin rest (Figure 4A). Three high-resolution LCD monitors were placed on a ramp such that the gaze angle (14.3 deg) was maintained at different viewing distances (Figure 4B). Monitor resolutions and sizes were chosen to vary letter size while maintaining pixel characteristics: at 33 cm, a 13.3" Macbook set to 1200*800 resolution was used, whereas a 20.5" IBM monitor was set to 640*480 resolution. The luminance level of each monitor was measured and adjusted so that the luminance was the same for each display condition. Apertures were used to cover the display frame to minimize accommodation bias due to the perceived size of the monitor. The distances and sizes of the apertures were calculated to allow binocular viewing of the test area. The room was lit at a recommended office-lighting level with an illumination (~250 lux for easy office work).

Outcome Measures

We calculated the difference between the before-task and after-task values for the five outcome measures: 1. reported symptoms, 2. lag or lead of accommodation, 3. accommodation accuracy during the lens flipper tests, 4. vergence accuracy during the prism flipper test, 5. near point of convergence. Static and dynamic accommodative and vergence responses (outcome 2-4) were measured mostly with Plusoptix Power Refractor II, using photoretinoscopy technology. The measurement station is shown in Figure 5. The measure of the retention of the task-induced changes was obtained for each of these outcome measures by calculating the area under the curve between 0 and 90 minutes after the task had been completed (t2 to t5 in Figure 6). Each set of measurements at each time point took about 6 minutes to complete:

1) Subjective rating of visual symptoms, including blurred vision, eyestrain, and eye irritation or tearing (*blur, strain, irritation*), using a 100-mm visual analog scale with four verbal anchors (slight, modest, bad, and severe).
2) Accuracy of static accommodation at distance (4 m, 0.25 D target): Measurement values were corrected for the bias due to gaze-angle differences that subjects had; lead and lag were the excess and reduced accommodative response relative to the demand specified by the target. The gaze-angle corrected lead (over-accommodation, positive measurement values) or lag (under-accommodation, negative measurement values) for a distant target *was* termed *DistLag* (in D).
3) Dynamic monocular accommodative response to the lens flipper (similar to an accommodation facility test) at the rate of 12 cpm for six cycles monocularly; this measurement test was adopted from the clinical accommodation facility test, where a + 2 D/ - 2 D lens flipper was used to alternate the accommodation demands while a subject was asked to keep the image of the target clear. The ability to compensate for the changing accommodation demands introduced by the lens flipper was measured by averaging the combined lead (during the plus lens phase) and the lag (during the minus

lens period) amount in 10 cycles of lens flipping monocularly. The larger the value, the less accurate the accommodation indicating that the less the subject was able to compensate for a dynamic accommodation change in that trial. We used monocular accommodation response, as that is a pure assessment of accommodative response without considering vergence, which occurs in binocular viewing. The monocular dynamic accommodation response accuracy was termed *AMD* (in D).

4) Divergence and convergence reflex fusion (similar to a vergence facility test) responses to 6 PD BI changing at the rate of 12 cpm for 10 cycles; the average vergence response to changing vergence demands was introduced by a 6 PD BI prism toggled in and out in front of a subject's right eye to cause a reflex divergence or convergence response. The vergence response here was determined from the IPD measurements recorded by the Power Refractor II, calculated from the pupil images from the camera. We calculated the average IPD difference in one 10-cycle divergence facility test. The dynamic divergence response was termed *VBD* (in mm for the IPD change; 1 mm IPD change was equivalent to an 8.33 PD vergence response).
5) Near point of convergence (*NPC*, in cm*)* is a standard clinical measurement of the amplitude of convergence. It is the distance where a subject cannot maintain a single image of a slowly approaching target. *NPC* is an indicator of the amount of convergence of an individual. The larger the value, the poorer is the ability to converge.

Data Analysis

All the accommodative and vergence responses measured by the Power Refractor were first analyzed in MATLAB: the average of each subject's response to the distant target during a 30-second period was obtained for *DistLag* calculations. The program defined the dynamic response cycles based on predetermined rates for each test and then calculated the average *AMD* and *VBD* responses. The pre- and post-task change (t2 minus t1) and retention measure (area under t2 to t5) were calculated as the summary measures for each outcome (Figure 6).

General Linear Models

Multivariate linear regression models were tested for each outcome variable and included indicators for the test conditions and one covariate (Table 1). Each test condition was a unique combination of viewing distance, lens power, and prism power. Distance had two states, lens had three states, and prism also had three states. Because the sample size was small and the experiment was not a full-factorial design, interaction terms were not included in the model, and only one covariate, divergence limit, was included. Condition 4, with the viewing distance of 100 cm and no lens and prism, was taken as the baseline.

Several subjects' visual characteristics were measured during the screening before the experiment. Divergence limit (*Divlimit*) was selected as a covariate for the models for a number of reasons. First, the divergence limit indicates how far a subject can diverge his or her eyes, which may affect preference for viewing distance. Second, based on the ZCSBV, the divergence limit is part of the upper-left boundary of the zone and had a narrower deviation range compared to the lower-left boundary of the zone. The divergence limit is expected to be a more sensitive predictor of symptoms. Third, this value indicates the balance of the strength of the eye muscles, which may then predict a subject's response to the prism. Finally, there was a wide distribution of divergence limit values in the test population, ranging from 6 PD to 14 PD, with the average of 8.71 PD and an SD of 2.34 PD.

Results

Comparison of Natural Viewing Conditions: Near vs. Far

All participants (N = 17) had normal visual acuity and binocular vision. Symptoms were typically minimal at the beginning of each test condition but increased during the 2-hour computer task, and the symptoms gradually resolved during the post-test period. An example of blurred vision over time is shown in Figure 7.

Two hours of computer work at 33 cm or 100 cm viewing distance did not show any significant changes in symptom or in the retention of symptoms. However, there were significant small changes in two of the objective measurements (Table 2). After performing the visual search task at 33 cm viewing distance, subjects showed a larger lead of accommodation (more negative refraction values) to the stimuli compared to the 100 cm viewing condition (Figure 8, $p = 0.038$). There were also weaker dynamic responses with less accurate vergence during the prism flipper process (Figure 9, $p = 0.030$).

Comparison of Lens and Prism Intervention

For a working distance of 30 cm, comparing Conditions 1 (with plano lens) and 2 (with +1 D lens), and Conditions 1 and 3 (with 6 PD BI prisms), we saw that decreasing accommodation demand with a lens or decreasing convergence demand with prisms did not result in changes in strain (Table 3). Therefore, low power lens or prisms to reduce accommodation or convergence demands at 33 cm did not have any significant effects on symptoms (Figure 10). However, comparing the results of the three conditions at 33 cm viewing distance, we saw that reducing the accommodation demand by introducing a plus lens induced more strain symptoms than reducing the convergence demand by using BI prisms (Figure 10, $p = 0.014$; adjusted $p = 0.015$). The retention of strain symptoms was also stronger for reduced accommodation demand (Condition 2) compared to the natural Condition 1 (adjusted $p = 0.0231$) or the reduced convergence demand (Condition 3) (adjusted $p = 0.004$) (Figure 11).

Multiple Regression

After using repeated measures ANOVA (RANOVA) in SAS 9.0 to compare results from different conditions, here we used the multiple regression coefficients to calculate the effects of each factor, which then could be related to distance, lens, and prisms as the source of the difference in visual demand. The outcome variables were either the pre- and post-task or the post-task retention values of the following outcome measures: *Blur, Strain, Irritation, DistLag, AMD, NPC,* and *VBD*. The indicator variables values coded for viewing distance (*NearDist*), lens power (*PlusLens*), and prisms power (*BIPrism*) for the six conditions are listed in Table 1. The regression model including the covariate divergence limit (*Divlimit*) is as follows:

$\underline{Y = \beta_0 + \beta_1 \, NearDist + \beta_2 \, PlusLens + \beta_3 \, BIPrism + \beta_4 \, Divlimit}$

Several coefficients were significant: (1) *Divlimit* coefficient of 0.42 (p = .001; R^2 = 0.31) for *Strain*; (2) *Neardist* coefficient of -0.12 (p = .034; R^2 = 0.04) for *VBD*; and (3) *Neardist* coefficient of -0.18 (p = .042; R^2 = 0.10) for *DistLag*. The regression results imply that, for every 4.2 PD difference in divergence limit, computer users' eye strain ratings after 2 hours of computer use increased about 10 mm on a 100 mm visual analog scale when the viewing distance and oculomotor demands remained the same. When the viewing distance for a 2-hour task changed from 100 cm to 33 cm, the dynamic divergence response to 6 PD BI prism for a near target decreased by about 1 PD (0.12 mm IPD change * 8.33 PD/mm of IPD change). When the viewing distance for the 2-hour task changed from 100 cm to 33 cm, the tendency to over-accommodate (i.e. lead of accommodation) for a distant target decreased by about 0.2 D.

Using the data from the 5 time points for 17 subjects performing 6 viewing conditions (n = 510), we found that objective measures of accommodative and convergence responses demonstrated only weak associations with subjective symptom ratings (Table 5).

Conclusions and Discussion

Findings

When the visual angle of the character size was maintained and other visual factors controlled for, the visual demand of a visual task depended on required accommodation and convergence. The 2-hour visual task using a computer monitor induced small changes in symptoms and some measures of accommodation and convergence. Some of these changes persisted for up to 90 minutes after exposure. The association between objective measures of oculomotor function and the symptoms was weak. The direction and the type of the effects depended both on the viewing distance and on the accommodation and vergence demands. Specifically, at the end of the 33 cm viewing task there was an increase in static accommodation response and a reduced dynamic divergence response, in comparison to the 100 cm condition. There were no differences in symptoms between the 33 and 100 cm viewing conditions. Optical manipulations of accommodation or convergence had no effect on the far viewing distance (100 cm), whereas changing the accommodation demand increased eyestrain at the near viewing distance.

In natural viewing conditions, the symptom changes were similar for the 33 cm and 100 cm distances. Previously, Sheedy et al. (2003) associated the symptoms: blurred vision, eyestrain, and irritation/tearing of the eyes, with a small font as well as accommodative and vergence stress. We controlled for the visual angle of the font and the perceived viewing distance from the monitor frame. This might explain why a viewing distance effect for symptoms, due to just font size, was not observed in our study. Under unnatural, modified demand viewing conditions, a decrease in 1 D accommodative demand (Condition 2) at 33 cm produced more of a post-task increase in eyestrain (p = 0.014) and longer retention (p = 0.0005) of eyestrain compared to eyestrain following a decrease in 6 PD convergence demand (Condition 3) or the natural viewing (Condition 1); however, the manipulation of the accommodative demand did not have an effect upon the symptom recovery at 100 cm. This highlights the limitation of the ZCSBV, which did not fully predict the influences of the viewing distance and accommodation and vergence demands on the development of visual symptoms.

Immediately after performing the task at a 33 cm viewing distance, there was an increase in accommodative response to a distant target (4 m). The over-accommodation did not occur at the 100 cm condition (Figure 8). This finding supports the phenomenon reported by Schor, Johnson, & Post (1984) that adaptation to a near stimulus for 30 minutes leads to a temporarily elevated level of tonic accommodation (i.e. resting focus of accommodation, or the focusing power of the eyes without the presence of accommodation stimuli). This change in accommodative state was short-lived and was not observed during the follow-up period. Interestingly, the change in accommodative state was not accompanied by an increase in subject-reported blurred vision rating. It may be that the amount of change (~0.2 D) was too small to be noted by subjects. The change was smaller than a tolerable blur (~0.5 D) and close to the smallest change in refractive power (0.25 D) used when determining prescriptions for spectacle glasses.

At the 100 cm viewing distance the dynamic divergence response was more pronounced than at the 33 cm condition ($p = 0.030$). This finding complements the the findings of a the previous study by Rempel et al. (2007). In that study, there was a larger dynamic convergence response at the closest viewing condition (52 cm) compared to the longer viewing distances (73 and 85 cm). Similarly, they found that the closer viewing distance was associated with improved convergence recovery compared to the longer viewing distances. In the current study, based on a general linear regression model, subjects' divergence limits were associated with the symptom eyestrain ($p = 0.001$). Thus, this characteristic of an individual may affect optimal viewing distance.

Limitations of the Study

Overall, the effects of viewing distance and viewing manipulation were less that what was expected. The literature supports the concept that accommodative amplitude decreases with fatigue. For example, accommodative amplitude was lower when subjects were stimulated by short-term (3 minutes) accommodation facility with -1.5 D to +1.5 D at a rate of 0.25 Hz or vergence facility and with 9 PD BO to 9 PD BI (Hasebe et al., 2001). However, we did not see a decline in accommodative amplitude across the 2-hour task. It may be that an accommodation reduction was offset by an accommodative spasm induced by the near-viewing task. With the pre-task and the four post-task testing trials, there may have been a significant training effect (strengthening the accommodation response) that could have offset any weakening of the accommodation response. Or, there may not have been any training or fatiguing effects throughout our measurement procedures. The effect induced by our test of accommodative response was expected to be less than had been observed previously because we used a faster alternation rates for the lenses and the prisms and our prism power was lower.

We also did not find significant difference in static convergence response (measured by *NPC*) across conditions. To some extent, the lack of effects or small effects observed may be due to the selection of subjects with normal oculomotor function. Approximately half of potential participants were excluded due to a phoria outside of clinical norms or pupils that cannot be found by the infrared camera. The task duration used in the study was only 2 hours. While most computer users spend longer hours during the day using a computer, the experiment still required sustained viewing of text on a screen that is likely more than required in the workplace. Another limitation was the low power of the study due to the small sample size.

Oculomotor functions are difficult to study partially because of the complex and adaptive nature of their system. There is synkinesis between accommodation and convergence responses; the oculomotor system is such that the accommodation and vergence responses are dependent upon each other; that is, accommodative changes produce vergence changes (accommodative vergence, referred to as the AC/A ratio) and vice versa (vergence accommodation, referred to as the CA/C ratio) (Schor & Tsuetaki, 1987). Difference in this ratio may affect a subject's response to optical manipulations through lens and prisms. This may be investigated in the future.

Figures and Tables

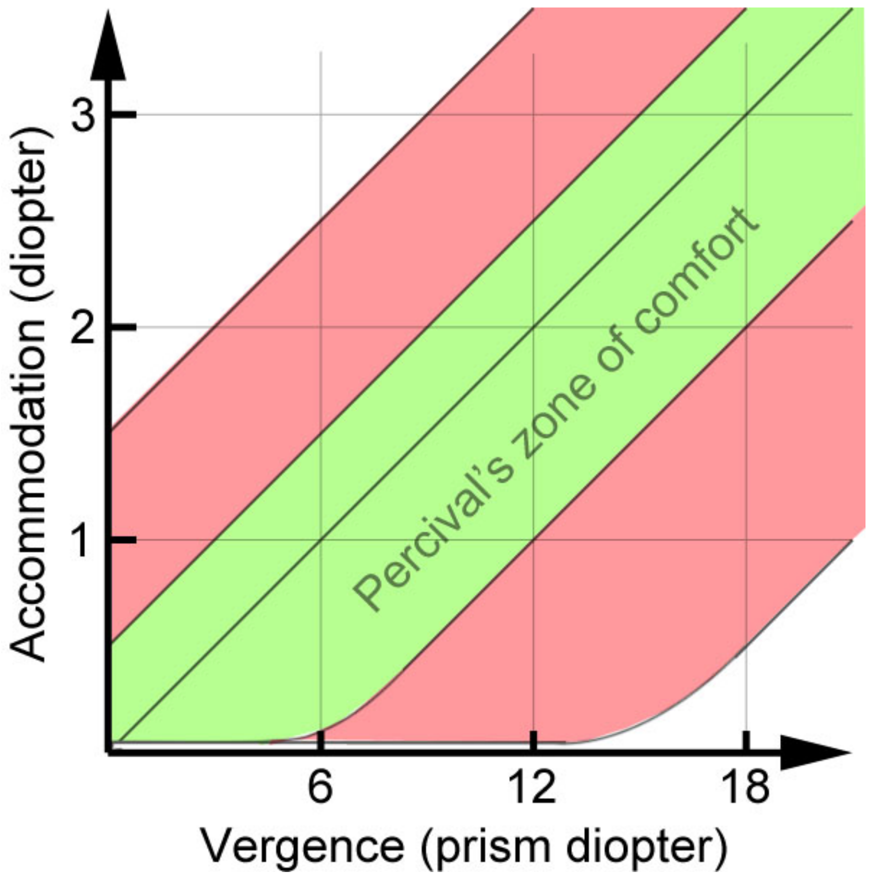


Figure 1. Zone of Clear Single Binocular Vision. Accommodation and vergence demands are proportional in the natural environment, so it is helpful for the visual system to couple accommodation and vergence response. The ZCSBV, indicated in pink, is the set of vergence and focus demands for which a typical viewer can adjust the visual responses sufficiently well enough to see a clear single image of the target even with the presence of demand conflicts. In particular, one can fuse stereo stimuli to see an image in depth without discomfort when the demands fall within Percival's zone of comfort, which is the middle third of the ZCSBV in which spectacle prescriptions should place natural stimuli inside utilizing prisms and lenses. In this figure, an IPD of 6 cm is assumed.

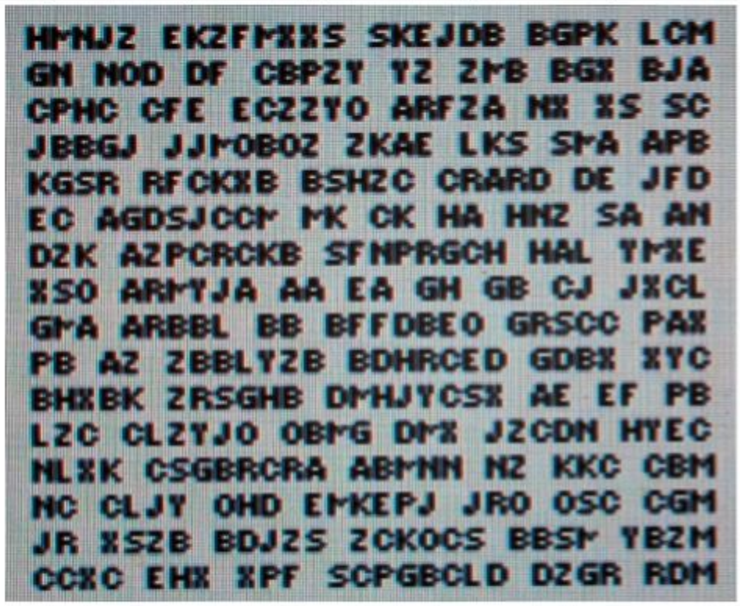
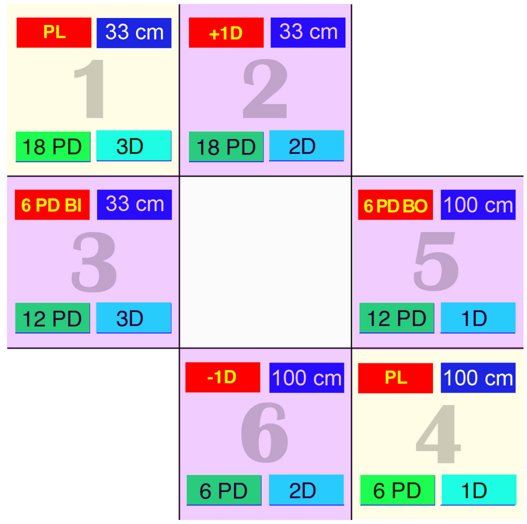


Figure 2. A Screen Shot of the Visual Task Used. In some conditions, the subjects looked at the monitor through low power lenses or prisms placed in front of the eyes on a lens holder.

A.



B.

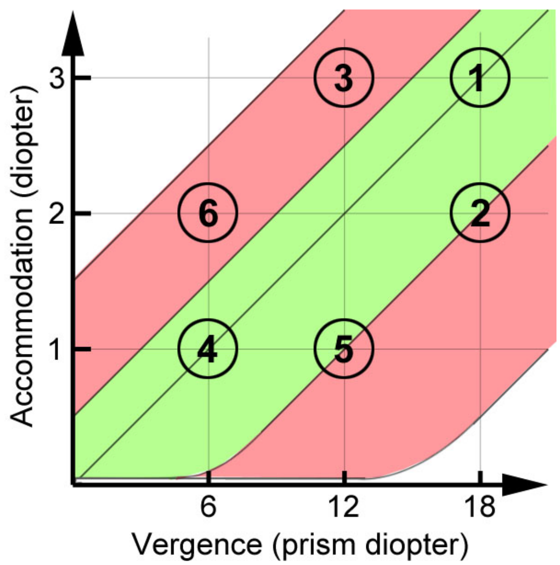
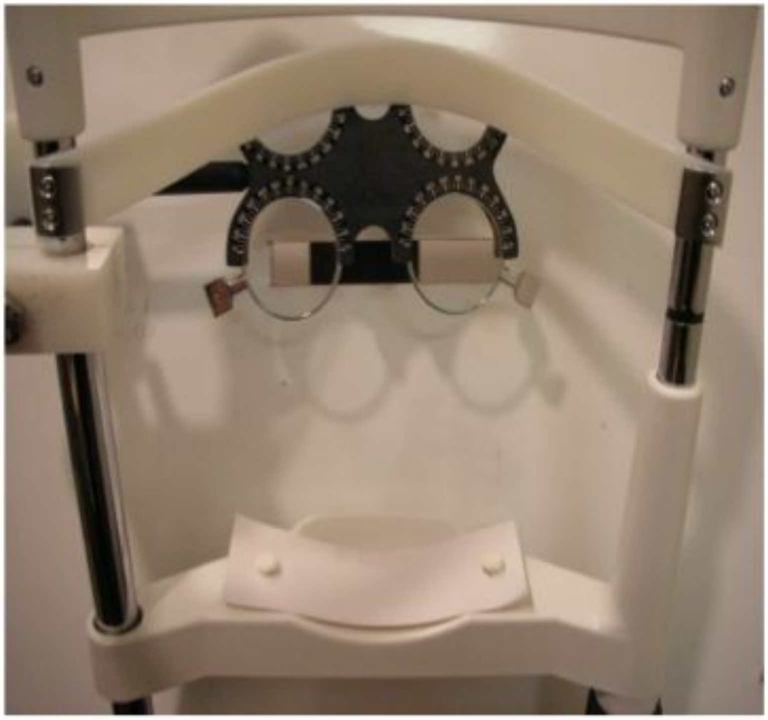


Figure 3. Six Experimental Conditions. A. The natural viewing conditions (conditions 1 and 4) at two different distances (33 cm and 100 cm) to the monitor are highlighted in light-yellow background. To test how conflicting accommodation and convergence demands would affect visual functions, we modified the accommodation demands by applying a positive or negative lens (+1 D, condition 2; -1 D, condition 6), or we changed the convergence demands by inserting a prism (6 PD BI, condition 3; 6 PD BO, condition 5). These unnatural viewing conditions are highlighted in pink background. Viewing distances for each condition are listed in dark-blue rectangles, prism, or lens types in red rectangles, accommodation demands are in light blue, and convergence demands are in green. The following abbreviations were utilized: PL: plano lens; BI: base-in prism; BO: base-out prism; PD: prism diopter; and D: diopter. B. The conditions are mapped on the accommodation-vergence demand plot.

A.



B.

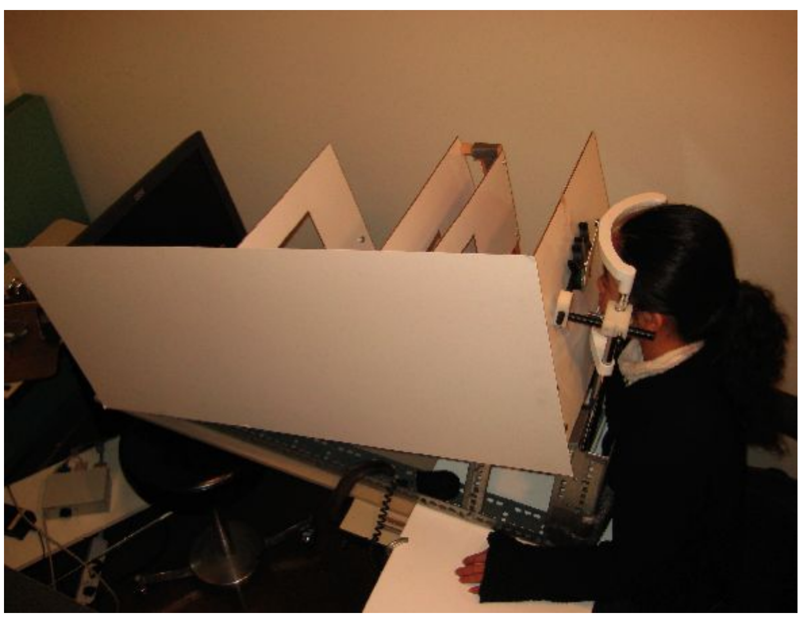


Figure 4**.** Workstation Setup. A. Chin Rest and Lens Holder; B. Workstation for Monitor Placement

Figure 5. Outcome Measure Workstation Setup. Plusoptix Power Refractor II (the black oval-shaped device close to the wall) was placed 1 meter away from the subject's eye (about where the black chin rest was). The distant target was presented in the mirror with an equivalent viewing distance of 4 meters. The slanted wood ruler was placed to the left and in front of the chin rest for a more accurate *NPC* measurement.

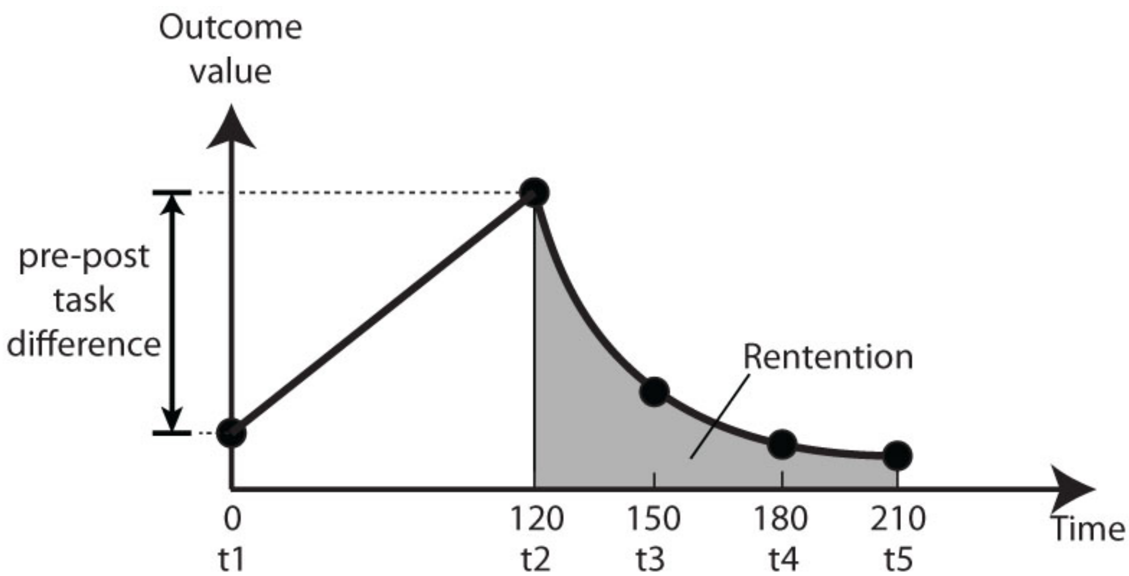


Figure 6. Pre- and Post-Change (t1 - t2) and the Retention Measure (the area under curve between t2 and t5) Were Calculated for Each Outcome Measure.

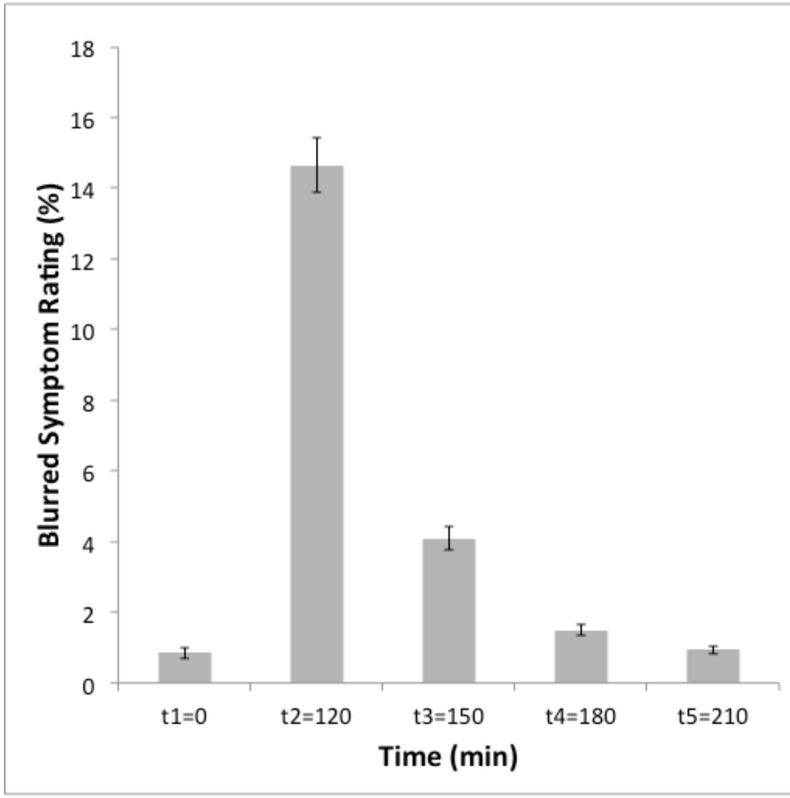


Figure 7. Mean Subjective Ratings of Blurred Vision Over Time Across All Viewing Conditions (n = 17). The symptom data were presented as the % of blur of on the 100-mm visual analog scale. The error bars represent SEM.

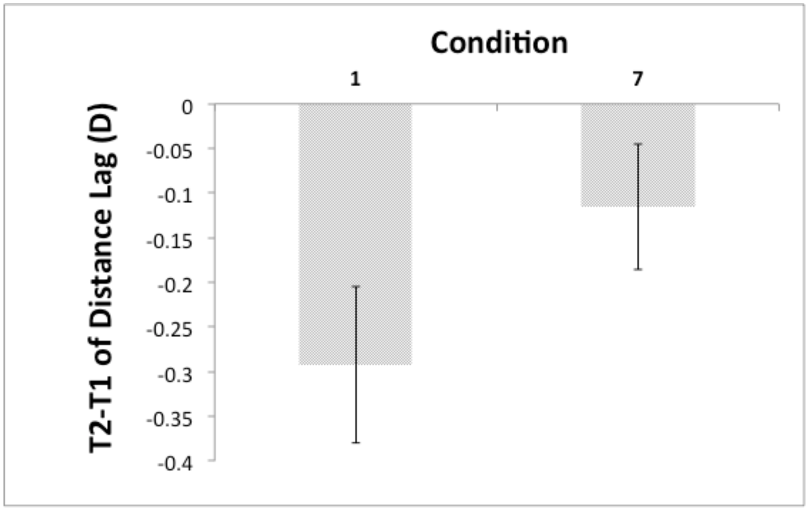


Figure 8. Pre-Post Task Changes in Accommodative Lead. Differences between the baseline and the post-task accommodative lead (negative accommodation value) for a 20/20 distant target at 4 m for two viewing distance conditions. Condition 1 is natural viewing at 33 cm and Condition 7 is natural viewing at 100 cm. The error bars represent SEM.

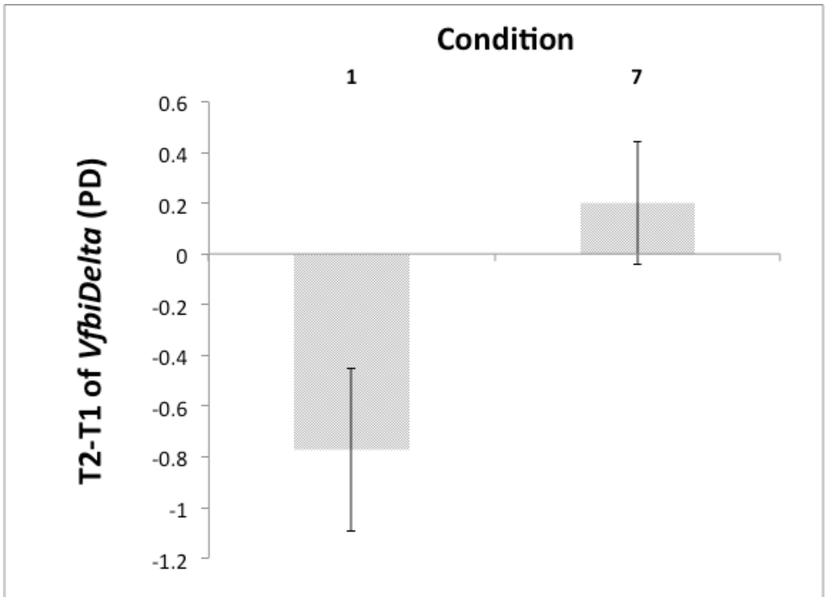


Figure 9. Pre-Post Task Changes in Dynamic Divergence Response (*VBD*). Differences between the baseline and the post-task dynamic divergence response amplitude for two viewing distance conditions (after converting 1 mm of IPD change to 8.33 PD change). Condition 1 is natural viewing at 33 cm and Condition 7 is natural viewing at 100 cm. The error bars represent SEM.

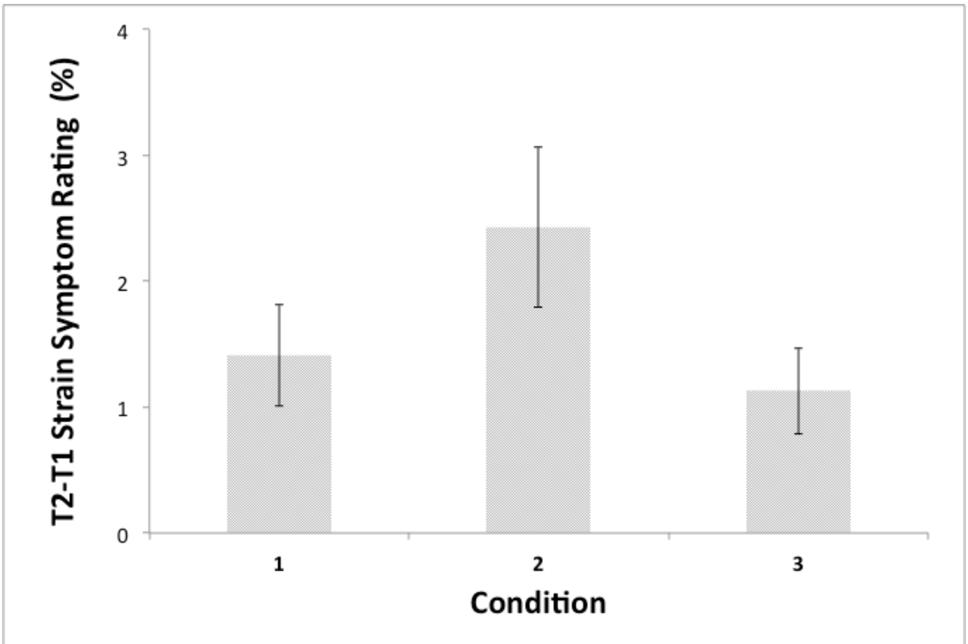


Figure 10. Pre-Post Task Changes in Eyestrain. Differences between the baseline and the post-task eyestrain symptom for three conditions at the near viewing distance. Condition 1 is natural viewing at 33 cm, Condition 2 is reduced accommodation demand at 33 cm, and Condition 3 is reduced convergence demand at 33 cm. The error bars represent SEM.

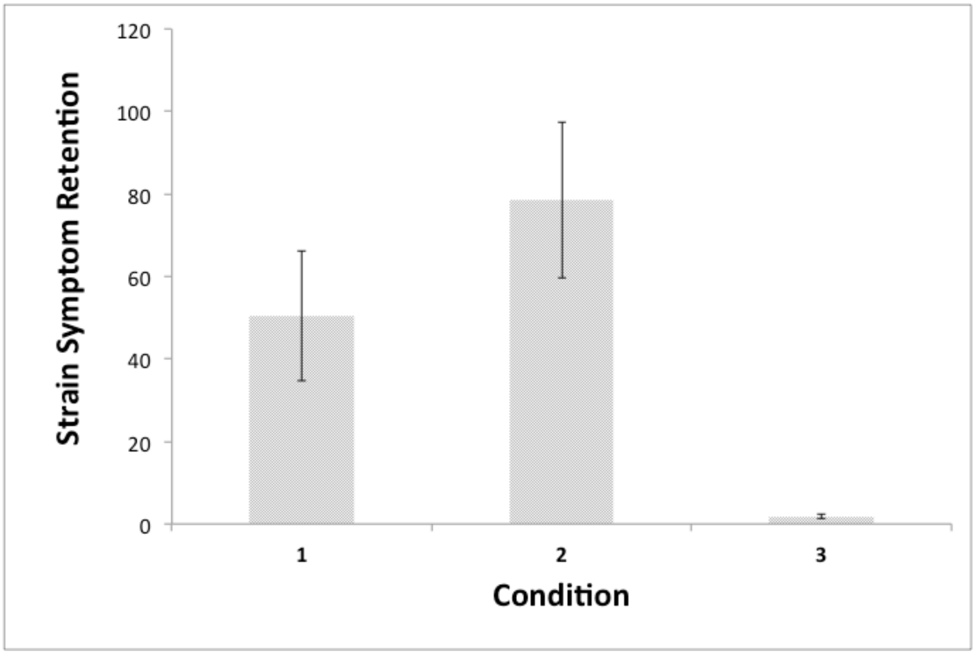


Figure 11. Eyestrain Retention. Strain symptom retention for three conditions at the near viewing distance. Condition 1 is natural viewing at 33 cm, Condition 2 is reduced accommodation demand at 33 cm, and Condition 3 is reduced convergence demand at 33 cm. The error bars represent SEM.

	Cond1	Cond2	Cond3	Cond4	Cond5	Cond6
NearDist	1	1	1	0	0	0
PlusLens	0	1	0	0	0	-1
BIPrisms	0	0	1	0	-1	0

Table 1.
The Indicator Variables for Distance, Lens, and Prisms to Code for the Six Conditions.

Outcome Pre-Post Difference	Condition 1 Mean	SD	Condition 4 p-value	SD	p-value
Blur	1.5	2.0	0.91	1.6	0.9
Strain	1.4	1.7	0.73	1.8	0.7
Irritation	0.5	1.0	0.43	1.3	0.4
DistLag	-0.3	0.4	0.038*	0.3	0.04*
AMD	-0.0	0.6	0.34	0.4	0.3
NPC	0.1	1.4	0.86	1.2	0.9
VBD	-0.1	0.2	0.030*	0.1	0.03*
Outcome Retention Measure	**Condition 1 Mean**	**SD**	**Condition 4 *p-value***	**SD**	***p-value***
Blur	46.8	60.3	0.34	54.9	0.3
Strain	50.4	64.6	0.11	88.7	0.1
Irritation	19.8	38.1	0.14	91.9	0.1
DistLag	105.8	89.6	0.19	80.7	0.2
AMD	218.1	54.1	0.11	62.3	0.1
NPC	899.1	189.5	0.62	244.1	0.6
VBD	146.6	27.6	0.87	28.2	0.9

Table 2.
Summary of Outcome Measures for Condition 1 and Condition 4. Condition 1 is natural viewing at 33 cm and Condition 4 is natural viewing at 100 cm. Significant differences between the condition are labeled with a * (RANOVA).

Outcome Pre-Post Difference	Condition 1 Mean	SD	Condition 2 Mean	SD	Condition 3 Mean	SD	*p-value*
Blur	1.5	2.0	1.9	2.1	0.7	1.0	0.055
Strain	1.4	1.7	2.4[a]	2.6	1.1[a]	1.4	0.014*
Irritation	0.5	1.0	1.2	1.9	0.4	0.9	0.066
DistLag	-0.3	0.4	-0.1	0.4	-0.2	0.3	0.16
AMD	-0.0	0.6	0.2	0.4	0.2	0.4	0.51
NPC	0.1	1.4	0.2	1.2	0.2	1.8	0.98
VBD	-0.1	0.2	-0.1	0.2	0.0	0.2	0.20
Outcome Retention Measure	**Condition 1 Mean**	**SD**	**Condition 2 Mean**	**SD**	**Condition 3 Mean**	**SD**	***p-value***
Blur	46.8	60.3	46.9	44.6	24.0	30.2	0.075
Strain	50.4[a]	64.6	78.5[ab]	77.8	34.9[b]	48.5	0.0005*
Irritation	19.8	38.1	32.5	49.2	16.3	39.3	0.20
DistLag	105.8	89.6	128.9	85.5	118.7	75.5	0.07
AMD	218.1	54.1	238.1	58.9	227.1	51.9	0.091
NPC	899.1	189.5	908.9	212.4	925.4	158.7	0.79
VBD	146.6	27.6	143.8	26.4	145.8	27.8	0.79

Table 3.
Summary of Outcome Measures for Condition 1, 2, and 3. Condition 1 is natural viewing at 33 cm, Condition 2 is reduced accommodation demand at 33 cm, and Condition 3 is reduced convergence demand at 33 cm. Significant differences between the condition are labeled with a * (RANOVA); significant differences between test conditions in a row are indicated by common superscripts (Tukey follow-up tests).

Outcome Pre-Post Difference	Condition 4 Mean	SD	Condition 5 Mean	SD	Condition 6 Mean	SD	*p-value*
Blur	1.5	1.6	1.4	1.6	1.3	2.0	0.80
Strain	1.5	1.8	1.8	2.1	1.2	1.4	0.34
Irritation	0.7	1.3	0.5	1.0	0.7	1.5	0.80
DistLag	-0.1	0.3	-0.2	0.4	0.0	0.3	0.078
AMD	0.2	0.4	-0.1	0.8	0.2	0.5	0.19
NPC	0.2	1.2	-0.1	0.7	0.4	1.3	0.48
VBD	0.0	0.1	0.1	0.2	0.0	0.2	0.76
Outcome Retention Measure	Condition 4 Mean	SD	Condition 5 Mean	SD	Condition 6 Mean	SD	*p-value*
Blur	38.3	54.9	34.2	34.9	50.6	71.9	0.24
Strain	69.5	88.7	78.3	108.2	80.0	111.4	0.81
Irritation	41.9	91.9	26.7	59.4	37.2	67.4	0.23
DistLag	119.5	80.7	125.2	84.0	119.8	80.7	0.54
AMD	235.6	62.3	208.7	48.3	217.5	52.1	0.072
NPC	921.0	244.1	919.3	239.4	906.5	206.6	0.87
VBD	147.2	28.2	142.6	25.7	141.2	23.8	0.16

Table 4.
Summary of Outcome Measures for Condition 4, 5, and 6. Condition 4 is natural viewing at 100 cm, Condition 5 is increased accommodation demand at 100 cm, and Condition 6 is increased convergence demand at 100 cm. No significant differences were found.

	Blur	*Strain*	*Irritation*	*NPC*	*VBD*	*AMD*	*DistLag*
Blur	1.00						
Strain	0.56	1.00					
Irritation	0.53	0.38	1.00				
NPC	0.029	-0.025	0.21	1.00			
VBD	-0.080	0.19	0.035	-0.0051	1.00		
AMD	-0.054	-0.064	-0.12	-0.098	-0.11	1.00	
DistLag	-0.096	-0.067	-0.064	-0.20	0.15	0.17	1.00

Table 5.
Correlation Coefficients of All Outcome Measures.
Correlation coefficients were obtained using the data from the 5 time points for 17 subjects performing 6 viewing conditions (n = 510).

Chapter 3

Effects of Font Size and Reflective Glare on Text-Based Task Performance of Presbyopic and Nonpresbyopic Computer Users

Abstract

Objective: Effects of presbyopia, font size, and reflective glare on performance of visually demanding text-based tasks on computer are investigated.
Background: Print size has a logarithmic relationship with reading speed at fixed viewing distances. It is unclear whether this relationship holds for natural viewing conditions for visually demanding text-based tasks where users' postures are not constrained. Reflections on a computer screen reduce contrast and may compromise productivity. The two effects may be different for those with and without presbyopia. Presbyopia is the loss of focus adjusting ability with increasing age.
Method: Nineteen young (18-35 year-old) and seven elder presbypoic (55-65 year-old) subjects participated in this full-factorial, repeated measures study with two trial factors: font size and reflective glare. The three font sizes of Arial type had capital letter heights of 1.78, 2.23, and 3.56 mm. The monitor location was fixed but subjects were allowed to move their bodies and the chair. Subjects performed visually demanding tasks that required similar visual skills to common tasks such as internet use, data entry, or word processing.
Results: Speed, accuracy and viewing distance increased as the font size increased. The average Visual Angle of Font (VAF) and Visual Acuity Reserve (VAR) at 3.56 mm capital font height was 23.4 arcmin and 6.1, respectively. There was significant productivity gain of 3 correct clicks/min and 8% of reduction in perceived task difficulty each 1 mm of font size increase ($p < 0.0001$), which was more pronounced in the young group. The presence of glare led to a reduced viewing distance.
Conclusions: For visually demanding computer tasks, productivity is improved when the font is increased from 2.23 to 3.56 mm. The larger font size corresponds to a VAF of 23.4, which is at the high end of ISO recommendations (International Organization for Standardization, 1992, 2011).
Application: The findings may be useful for settings the default font size for computers and for training of office workers on the font sizes they should select for their applications.

Introduction

According to US Census Bureau's Current Population Survey (CPS) data in 2003, 56% of all employed individuals use computers at work; this number was as high as about 80% in some professions, such as management, business, and finance (Day et al., 2005). Among workers' reports of discomfort during computer use, visual issues have been most common (Faucett & Rempel, 1994; Sheedy, 1992). From the employer's standpoint, visual and physical symptoms should be minimized because they are a source of reduced performance, lost work-time, employee turnover and worker's compensation costs. Performance at the workplace is commonly quantified by productivity (rate of work done) and accuracy (fraction of work done correctly).

Daum et al. (2004) demonstrated that even minor vision problems such as modest amounts of blur due to astigmatic refractive error could result in lower performance. At the workplace, other individual and environmental factors such as presbyopia, font size, and reflective glare may also affect visual performance and thus job performance. However, these effects have not been well quantified.

Multiple psychophysical studies have shown that larger font size is associated with faster reading speeds (Lee et al., 2008; Legge et al., 1985; Legge & Bigelow, 2011; Levi, 2008; Levi & Carney, 2009; Whitney & Levi, 2011; Whittaker & Lovie-Kitchin, 1993). For a given sample of print, the visual acuity reserve (VAR) is the ratio of the print size angle to the visual acuity (VA) threshold for identifying letters. It was suggested that, for printed materials, reading speed has a logarithmic relationship with VAR , and that this relationship holds up to a critical print size of about four times of the size at the visual acuity threshold of the viewer (Bowers & Reid, 1997; Yager, Aquilante, & Plass, 1998). For these studies the viewing distance was constrained. It would be useful to verify these findings under more naturalistic experimental conditions allowing subjects to select their preferred posture and viewing distance.

Visual Angle of Font (VAF) can be expressed as the ratio of the font height to viewing distance. There have been several recommendations for the range of VAF that should be used by normally sighted observers and these are mostly between 16-22 arcmin range (Eastman Kodak Company, 2004; International Organization for Standardization, 1992, 2011; Sanders & McCormick, 1993). As Legge reported, an x-height of 12 minarc (e.g., 1.75 mm at 50 cm viewing distance) is a consensus critical print size value for normally sighted readers. Based on the default setting of the Safari web browser on a MacBook Pro (132 pixel per inch), the average lowercase x-height of online newsletter main texts would be 0.21° (1.5 mm viewed at 40 cm; range 0.16°- 0.25°) (Gordon E. Legge, 2006) - This only gives a VAF of 10.3 arcmin at 50 cm, which is lower than the recommended values.

Often in the workplace, with the most common combinations of a screen size, and displays of text, the character size typically has an x-height of about 3.3 mm (Rempel et al. 2007). For print of this size, it is recommended by Rempel et al. that the computer monitor be positioned between 52-73 cm distances from the eyes rather than further or nearer. This is because prolonged computer viewing distance closer to 50 cm may lead to visual symptoms due to higher convergence demand, particularly for people who have near convergence issues (Rempel et al., 2007). However, for small font sizes, shorter viewing distance should be adopted to improve readability. This experiment allowed freely adjustment of the body and the chair and examined the effect of font size on viewing distance, VAF, and VAR.

Presbyopia is an age related reduction in the ability for the eye to adjust focus (accommodate) as a result of the increase in size and stiffening of the lens of the eye) (Fisher, 1973; Glasser & Campbell, 1998; Schachar, 2006). Typically, presbyopia is manifest as reduced ability to focus on near objects, but it also leads to a limited range of viewing distance and compromised visual acuity if uncorrected. Presbyopia increases with age and is present in almost all people over 40 years old. Since presbyopes have a limited range of viewing distance and computer displays have default font sizes that users tend not to change, a study to clarify these two potentially related factors is needed.

Reflections on a computer screen, that is, seeing reflected images of light sources on the screen, has the potential to affect visibility and interfere with productivity. The reflection, which can be characterized as image glare, can reduce target image contrast and lead to visual distraction and the shifting of focus between the task and the distant light source. The glare may be localized on the screen (area glare) or a uniform glare spread evenly over the whole screen surface. Often, these reflections are not immediately noticed. However, if the glare is strong or localized it may be disabling (e.g., reduces visual acuity) or induce discomfort (Sheedy et al., 2005). Therefore, lighting in the office is an important environmental factor. In the workplace, reflective glare resulting from nearby light sources reflecting off the monitor is one of the most frequent complaints related to computer use (Bernecker et al., 1993; North, 1991). Depending on the level of the intensity and the type of light source, reflective glare in the office environment may affect visual performance differently. A simulated office lighting experiment with 18 to 58 year-old subjects (Veitch, 2001) found that workers prefer working in offices with windows, having electric lights during the day even in the office with windows, and have less preference for a darker room with a task lights besides the computer (Veitch, 2001). The demands of energy conservation have caused LEDs lights to start replacing incandescent and fluroscent luminaries. Liu, Chiang, & Lin (2010) suggested that LEDs, compared to fluorescent lamps given the same illumination levels (both did not produce glare), had less subjective fatigue reports and higher productivity from the young subjects performing computer tasks.

There is some evidence that glare may interfere more with productivity for the older than the younger worker. Bailey and Bullimore (1991) reported that older subjects (mean of 64.9 years) have lower visual performance (i.e. lower visual acuity) and may, therefore, be more susceptible to disability glare than younger subjects (mean of 28.4 years of age). Sheedy et al. (2005) reported that older subjects (mean of 55.5 years of age) take longer to perform a visual task requiring repetitive transitions between brighter and dimmer areas than younger subjects (mean of 27.9 years of age). These studies suggest that older people may have lower productivity on a computer task when viewing a screen with uneven luminance as a result of reflective glare, but this theory has not been tested.

This study examines the effects of presbyopia, font size, and reflective glare on visual performance during visually intensive computer based tasks. The null hypothesis is that font size and reflective glare do not reduce productivity or accuracy. In addition, this hypothesis is not affected by the presence or absence of presbyopia. The findings may provide guidelines for the setup of computers to improve productivity and comfort.

Method

Participants

Participants were recruited from flyers placed on the campus and in the community. Interested recruits were screened and were included if they were 18 to 35 or 55 to 65 years old with at least 20/20 visual acuity and were experienced in using a mouse on a computer. The presbyopic subjects (age 55 to 65) were required to wear their usual multifocal or progressive addition lens (PALs) during the experiment. Exclusion criteria were recent or chronic musculoskeletal pain or vision diseases. The study was approved by the UC Berkeley Committee for the Protection of Human Subjects and subjects signed an informed consent form.

There were seven participants in the presbyopic group (ages 55-65) and 19 participants in the pre-presbyopic group (ages 18-35). Subjects completed a survey on demographic, general physical health related to musculoskeletal symptoms, and visual corrections. Their letter chart visual acuity was measured at four distances (40, 63, 100, 400 cm) with Colenbrander Mixed Contrast Letter Chart for reading (40cm), computer (63cm), and intermediate (100cm) distances. Contrast sensitivity for small letters was measured using the Super Vision Test chart at four meters (Precision Vision, La Salle, IL).

Experimental Design and Procedures

This was a full-factorial, repeated measures experiment with two factors, font sizes and glare. The three levels of Arial font size tested were small (S): 1.78 mm (capital letter height on screen was 8 pt), medium (M): 2.23 mm (10 pt), and large (L): 3.56 mm (16 pt). Small-medium, medium-large, and small-large fonts differences are 0.1, 0.2, and 0.3 log units apart, which is 1, 2, and 3 lines in on visual acuity chart respectively. The two levels of glare tested were no glare (N) and glare (G). The order of testing of the six test conditions was randomized using a computer based random number generator.

Subjects performed three different visually intensive tasks for all 6 test conditions and for each test condition performance measures were averaged across the three tasks. The three tasks were a visual search task (V) and two matching and selection tasks, the abridged MN task (A), and the hard MN task (H) (Figure 1). The visual search task required subjects to identify the spaces, in a block of nonsense words, for which the same letter was on both sides of the space. The two matching selection tasks, abridged MN and the hard MN tasks, required memorizing a template nonsense "word" consisting of some combination the letters "M" and "N" and identifying a matching "word" from four options. The average "word" lengths for the abridged and the hard MN tasks were three and five letters, respectively. The duration of each test condition was 21 min. Additionally, each session started with one baseline trial (V task with the L-N condition, the easiest combination of trial factors) for five minutes. After each test condition, subjects filled out a brief survey for symptoms and subjective difficulty ratings. Subjects took a 15-minute break after each test condition. For each subject, the experiment lasted about 3 hours, not including a half-hour setup time.

The automated experiment procedure was run by National Instruments LabVIEW7 to generate random trial order, control for trial timing, displaying task images (screen capture of Microsoft Word font at 100% zoom), and record responses for further analysis. The three tasks were generated and presented to subjects using Microsoft Word and National Instruments LabVIEW7. The visual search task was transcribed from a customized software (Wolfgang Jaschinski, 2002; Rempel, Willms, Anshel, et al., 2007) that produced 50% matching letters rate for each page with average word length of five letters.

For each page of each task, the block of text generated in LabVIEW was entered into a Microsoft Word document at 100% zoom and saved as a screenshot in a Portable Network Graphics (.png) file. The graphics files were then imported as pictures into

LabVIEW for displaying to test subjects. Subjects left-clicked to indicate correct answers. Click locations and timestamps were recorded in Excel and later analyzed in MATLAB for correctness. A correct click had to be within two pixels of the border of the correct space. No feedback was given during the experimental session, only in a practice session to ensure familiarity with the precision requirements of the task. The subjects were informed that their responses would be recorded and they were to work as rapidly and as accurately as possible.

Workstation Setup

The tasks were performed under average office lighting (~500 Lux on the work surface, LX-1108-CAL CERT Lux/Footcandle Light Meter, D.A.S. Distribution, Inc.) with no windows or extraneous sources of glare. The monitor was a 20.1-inch LCD flat-panel monitor (Model 2007FPb, Dell) driven with a graphics card (Matrox Millennium G450 Dual Head LX) set at analog quality, 24-bit color, 1600 x 1200 resolution, and a 60 Hz refresh rate. The monitor was mounted on a custom-made monitor stand that allowed height and tilt adjustments. The chair (Model 462LEAP19L (Leap), Steelcase, Grand Rapids, MI) height was adjusted for hip and knee angles of 90º. The chair and work surface were adjusted so that the elbows were supported on the chair arm-rests, with the forearms near horizontal, and the palms resting on the table surface. The mouse was located to minimize shoulder flexion and abduction. While the subject was in a slightly reclined position, the monitor was positioned for an initial viewing distance (VD, eye-to-monitor) of 63 cm; the center of the monitor was positioned so the vertical gaze angle was 15º below the horizon from the eyes. The task area was a 5 cm x 16 cm area in the center of the monitor where the task characters were displayed. During the experiment, subjects could change the chair position and their posture but could not change the chair height or the monitor location or tilt.

The source of added reflective glare was a pre-made LED luminary with 72 LED arranged in a 3 by 24 array amounted within a rectangular that was 21.5 cm by 5.6 cm (Shanghai Raylin International Trade Co., Ltd, Shanghai, 5 mm round type, emitting white color, viewing angle 15°, luminious intensity 13500 millicandela). It was positioned above and behind the subject as in Figure 2 to produce an area glare on the matte monitor that has no detailed reflection patterns that would appear if the reflections were on a glossy screen. Here the location of the glare source and the location and tilt angle of the monitor were arranged to maximize the perceived glare in the central region of the monitor. This glare setup produced undesired area glare that reduced contrast at the normal range of viewing angles described by the Illuminating Engineering Society of North America (IESNA); for a standard setup for a screen tilt of 30° from vertical, it is recommended that the luminaires are positioned behind and above one from a luminary-screen angle at least -35° angle from horizon (IESNA Office Lighting Committee, 1993). But the luminary-screen angle in this study was -34° angel from the horizon.

The luminance contrast was calculated from the luminance values measured with photometer (CS-100, Minolta). Five points on the monitor were measured for their luminance contrast: the center of the screen and the four corners of the task area. With the monitor on, luminance of the five 20 mm black circles (L_{min}) and the adjacent white areas (L_{max}) were measured with and without the glare source on. The photometer was mounted on a tripod pointed at the target area on the monitor at a distance of 40 cm, 50 cm, or 67 cm from either 0° or 15° to the right of the center line of sight with a viewing angle either perpendicular to the monitor or 15° above the perpendicular line. Both with and without the glare, the Michelson contrast ratio was calculated using the equation: (*Lmax* - *Lmin*) / (*Lmax* + *Lmin*) (ISO 9241-3:1992 (E) 2.22). The percent reduction in the contrast ratio due to glare was then calculated. Along the centered line of sight and with a viewing angle perpendicular to the monitor, the presence of glare reduced contrast at the center of the monitor from 0.83 to 0.28, a 67.5% reduction and most among all the measurements; the luminance increase on the screen due to the glare was about 188 cd/m^2, much larger than 40 cd/m^2, a level that is considered a significant reflective glare in the office environment (Veitch, 2001). All other points have a contrast reduction less than 0.05 (10%), except those measured from the right corners of the task area, of which the reductions were slightly higher, but still less than 0.25 (30%). Little (<10 cd/m^2) or no increase in luminance was detected in these areas. This contrast ratio reduction was consistent across the three distances from the monitor.

Outcome Measures

The three primary outcome measures were subjective ratings of productivity, accuracy, and subjective ratings of task difficulty. For each trial, productivity was measured as the number of correct clicks per minute. For the abridged MN task and hard MN task, a correct click involved selecting the answer choice that matched the template. For the visual search task, this involved clicking on spaces with the same letter before and after the space. Accuracy was the percentage of clicks that were correct clicks. After each trial, subjects rated the task difficulty using a visual analogue scale slider displayed on the screen with verbal anchors “None” and “Severe” on either end of the scale.

A secondary outcome measure was viewing distance (VD), which was continuously recorded at 30 Hz using an active motion capture system with two monitor banks (OptoTrak 3020, Northern Digital, Ontario, Canada). A clutter of three infrared emitting diodes (IREDs) on a small light weight triangle plate with a side length of about 2 cm were secured just anterior to the subjects' ear on the cheek near tragus. These were used to identify the representative point for the eyes, that is, the point on the ridge just above the nose between the two eyes. The calculated distance between the representative eye point and the center of the monitor was the VD (Figure 2).

The intermediate variables explaining the effect of the trial factors and were the visual angle of font (VAF) and visual acuity reserve (VAR). VAR is the ratio of VAF to the subject's visual acuity. Visual Angle of Font (VAF) was estimated using:

*VAF (arcmin)= 57.3 * 60* font height (mm) / viewing distance (mm)*

Visual Acuity Reserve (VAR) is the ratio of VAF to the subject's visual acuity. In the analysis, we used the VA at 40 cm; since a 20/20 letter subtends 5 arcmin, the letter height at 40 cm for the visual acuity of 20/X is X/4 arcmin. Therefore, the VAR calculation for our study is:

VAR = VAF / VA
*= 57.3 * 60 * (font height / viewing distance) / (X / 4)*
*= 13752 * font height (mm) / [viewing distance (mm) *X]*

Statistical Analysis

Differences among the factor levels for all outcome measures were initially evaluated by repeated measures ANOVA (RANOVA) using the framework of general linear models with the *PROC GLM* command in SAS 9.0. Presbyopic status was used as a grouping factor while font and glare were the trial factors; the model included the independent effect of each factor and the two-way interaction terms between these factors. Presbyopic factor had no significant effect in the models so it was removed from subsequent models. Factors and interactions with significant F tests for fixed effects were followed up with Tukey's multiple comparisons. In the above models, font size is treated as a categorical variable. To investigate the effects of font size as a continuous variable, the dichotomous glare variable, along with VAF and VAR on productivity, a random effects general linear model was used to evaluate the independent effects of font and glare and their interaction (*xtreg* command, account for repeated measures; STATA 10). The font-glare interaction term was dropped from the final model because the coefficient was not statistically significant and it did not improve the fit statistics.

Results

This study demonstrated a productivity (i.e., speed = number of correct clicks per minute) improvement when using a large font size compared to smaller font sizes under natural viewing conditions for computer users performing visually demanding tasks. The glare setting used led to a reduction in viewing distance but not task performance. There was no significant effect of presbyopia on productivity ($p = 0.40$), accuracy ($p = 0.59$), or perceived task difficulty ($p = 0.93$), so this grouping factor was removed from the remaining analyses. And this suggested that the presbyopic subjects did not have much blur that was significant compared to the young subjects.

Font Size and Glare Effects on Task Performance

Font size had significant effects on productivity, accuracy and perceived task difficulty (Table 1, Figure 3). Both speed and accuracy were improved in the large font condition compared to the two smaller font sizes. Tasks were perceived as easier in larger font sizes than in the smaller font sizes. Neither glare by itself nor the font size by glare interaction term had a significant effect on the performance measures or perceived task difficulty.

Font Size and Glare Effects on Viewing Distance, VAF, VAR

Subjects significantly reduced their viewing distance when the font was smaller or the glare was present (Table 2). The reduced viewing distance modified the effect of font size and glare on the intermediate variables, VAF and VAR (Table 2). There was no significant effect of the font size by glare interaction term. Based on the Tukey follow-up tests, the effect of font on viewing distance was significantly different between each of the font size comparison pairs, indicating the smallest font size difference that will affect these outcome measures is 0.1 log unit, which correspond to one line difference on a visual acuity chart. Comparing the actual to the hypothetical VAFs (e.g., based on the subjects reduced viewing distance at the smaller font conditions vs. hypothetical situation where the viewing distance was not changed from the large font size condition), the actual VAFs were greater than the ISO minimum recommendation of 16 arcmin (International Organization for Standardization, 1992, 2011) (Figure 4). The relationship between speed and VAF is similar to that of speed and font size, where productivity was significantly higher in the largest font condition (Table 1). The comparisons between the glare groups indicated that subjects may have increased VAF, by moving forward, in order to avoid the effects of the glare and to maintain their productivity (Figure 5).

General linear models were used to explore the relationships between font size, VAF and VAR and the outcome measures productivity, accuracy and perceived task difficulty (Table 3). Font size, VAF and VAR were better predictors of productivity than accuracy and perceived task difficulty. More of the variance in productivity was explained with font size and VAR than VAF and adding glare to the model did not improve model prediction. Based on the beta coefficients, each mm increase in font height increased productivity by 2.55 correct clicks/min and each arcmin of VAF increased productivity by 0.43 correct clicks/min. Similarly, each mm increase in font height can reduce perceived task difficulty by ~7.75%.

Conclusions and Discussion

Productivity

Data processing is a critical part of most business processes. The ability to perform visually demanding computer based tasks accurately and quickly is important for organizational function. This study found that small increases in font size can increase the speed and accuracy of visually demanding computer based tasks. By increasing font size by 0.3 log unit, or 100%, from 1.78mm to 3.56mm, there was a 30% increase in productivity from 14.2 correct clicks/min to 18.5 correct clicks/min.

The 30% improvement in productivity that we observed, with the 3.56 mm font compared to a 1.78 mm font, is at the high end of the productivity increase (2.5% - 28.7%) that was observed by Daum et al. (2004) with astigmatic refractive correction. Based on their cost-benefit analysis on the visual correction ($268 estimate) of an employee with a salary of 25,000 dollars per year, a conservative estimate of 2.5% increase in productivity provides a favorable cost-benefit ratio of 2.3. Compared to Daum et al., the visual search task used in our study is similar to their “manuscript editing” task, which required the subject to find a certain character within a block of text, and the other two matching selection tasks were closer to their “county population listing” and “m and n word search,” which involved matching letters or numbers to a template in a tabulated format (Daum et al., 2004). All of the tasks demand similar visual skills and various levels of memorization to common more-visual activities, such as Internet use, data entry, or word processing. In our study, an increase in 30% productivity may be associated with 65% increase in VAF from 14.2 arcmin to 23.4 arcmin and/or 65% VAR from 3.7 to 6.1.

Perceived Task Difficulty

The smallest font size difference tested in our study (0.1 log unit, 0.43mm, 25% of font size increase from 1.78 mm to 2.23 mm, Table 1) was able to be perceived by the subjects as a decline in task difficulty but it did not lead to a significant difference in speed. This suggests that subjective ratings may be more sensitive than the objective productivity measures. This agrees with the findings by industry studies that usually smaller change in a design variable would induce perceivable differences in task performance before significant difference in performance was measured as a result of bigger change in the parameter. Therefore subjective rating remains an important measure for evaluation of display settings.

Font Size Effect on VD

It was reported in a recent study using Chinese characters and an electronic paper display that age had an effect on preferred viewing distance (50.3, 45.5, and 44.4 cm for the young, middle age and older group, respectively) (Daum et al., 2004). In our study, the average viewing distance observed for the younger and older group were 47.4 cm and 56.3 cm, respectively, but the differences were not significant. The differences may be due to differences in prescription of the elder group. Reading glasses affect the refractive state of the elderly and, assuming normal 0.5 diopter tolerance of blur, + 1.5 diopter gives 50 - 100 cm as the range of clear vision, while + 2.0 diopter gives 40 – 66 cm range of clear vision. In our study, the prescription powers of the presbyopic subjects were mostly +1.5 diopter while the prescriptions of the subjects were not stated in the paper by Wu. The self-selected viewing distances in our study were 53.9 (SD = 9.9) cm for the large font condition (3.56 mm) and 44.8 (SD = 8.9) cm for the small font condition (1.78 mm). It was suggested that enlarging font size may help the subjects to adopt a longer viewing distance (Rempel et al. 2007).

Font Size Effect on VAF

Several standards have recommendations for suitable VAF for reading text on computer monitors, mostly ranging from 14–22 arcmin: ISO 9241-3 (1992) recommended 20–22 arcmin as a preferred VAF (capital size). The *Kodak* ergonomic handbook (2004) recommends 14–22 arcmin. BSR/HFES 100 draft standard (2002) recommends 16–18 arcmin. Sanders & McCormick Human Factors handbook (1993) recommends 16–22 arcmin range. In the ISO standard for electronic visual displays (2011), ISO 9241-303:2011(E), it is suggested that minimum Latin character height shall be 16 arcmin and the upper limit height should be 30 arcmin when readability is critical.

The VAF range reported in this study (14.2, 16.4, and 23.4 arcmin) mostly fell in the acceptable range of the ISO-9241-3 but outside of the optimal recommendation (20–22 arcmin). Currently, the system is required to have the capability of providing a character height from 20–22 arcmin for Latin characters (International Organization for Standardization, 2011). VAF was slightly higher in the glare condition than that in the no-glare condition (18.6 vs. 17.4 arcmin, $p < 0.0001$). A VAF of 22–23 arcmin has been previously reported with 5-mm characters and preferred distance of 74cm (Jaschinski-Kruza, 1991) and a study by Rempel et al. (2007), in which subjects performed a combination of the same visual search task with a fixed font height of 3.3 mm and internet search. The viewing distances reported in the latter study could be modified by body posture only because the subjects were not allowed to move the chair. Our results suggested that when individuals can freely adjust posture and the chair, which is more natural, a larger VAR is preferred.

In our study, with 1.78 mm font height, the viewing distance (44.8 cm) was close to the typically preferred viewing distance of 50 cm for monitors (Legge & Bigelow, 2011). This may due to the fact that subjects may not want to get much closer to the monitor because increase of accommodation and convergence demands and not the most preferred VAF/VAR. On the other hand, it was also suggested that in a recent study investigating preferred viewing distance of electronic paper displays that the preferred longer viewing distance becomes longer as the character height is increased but only up to 3.2 mm (Shieh & Lee, 2007); in their study, 2.4, 3.2, 3.7, and 4.3 mm font height subtended 16.7, 22.2, 25.7, and 29.9 arcmin, respectively at the preferred viewing distance of 49.5 cm. Therefore, considering both the productivity benefit, it is recommended to adopt font size that allow slightly above 22 arcmin when the viewing distance is more than 50 cm while using desktop computer at work, especially when the task is visually and cognitively demanding.

Font Size Effect on VAR

It is recommended that monitor placement recommendation should take font size and visual acuity into account; Whittaker & Lovie-Kitchin (1993) reported that, to achieve high fluent reading rate for 4–6 characters per word at 174 words per minute (wpm), the acuity reserve ratio needs to be at least 3:1. They also suggested that the optimal would be at least 6:1, which was only achieved in the large font size (VAR 6.1 and VAF 23.4 arcmin) with highest speed and most consistently high accuracy in this study.

Glare Effect on VD, VAF, and VAR

Even though our glare setup falls within standard setup suggested by the IESNA Office Lighting Committee (1993), our observation that subjects move toward the screen when on screen reflective glare is present, has not, as far as we know, been reported by other researchers. It is most likely that subjects move forward and reduce the viewing distance and increase VAF and VAR to mitigate the reduction of contrast from glare. It is also possible that subjects moved forward to change the glare-monitor- eye geometry to reduce the reflective glare from the reading area. However, in this experiment setup, the subject could not create a shadow of the glare source by moving the head forward. Previous studies mostly characterize the luminance of the light source without quantifying the glare perceived by the viewers (Sheedy 2005; Bailey & Bullimore, 1991). Our study provides information regarding the actual luminance within common volume of working space. Some effects may become more prominent with a longer exposure time. In a study evaluating participants' preferences for lighting in an open plan office environment at the beginning or the end of the day, participants chose lighting conditions that produced less monitor screen glare if they made the choice at the end of the day, which implies that glare were more bothersome after prolonged computer work (Veitch, 2001). Aging eyes have been thought to have less tolerance to glare, however, self-reported glare discomfort rating are mixed (Shi, Lockhart, & Arbab, 2008). In our study, we did not find an age-dependent effect of glare. This may be because the subjects' contrast sensitivity in our study was normal and compatible to young subjects.

Limitations of the Study

There are several limitations of this study: First, the productivity measure is mostly applicable to visually tasks with little other mental operation/cognitive demands, which may have independent or interactions with the other factors. In addition, there is a tradeoff between the amount of content being fit into one screen and the readability; therefore larger font may limit productivity while one performs real tasks. Second, it is unclear how the viewing distance would vary with even smaller fonts capable of being displayed on higher resolution monitors and smaller handheld devices when other factors affect viewing distance are present, such as monitor size and accommodation limit beyond one's accommodation limit. Third, reflective glare in an office environment can vary, possibly covers larger and multiple screen areas. This would make the glare-mitigating behavior harder to predict. Also, we used a monitor with matte surface so the effect of glare may be smaller compared to when one uses a glossy screen, which would produce a brighter reflection with more detailed patterns of the reflected images. Last but not least, current recommendation use capital letters, but 94.5 % of English texts are lowercase (Jones & Mewhort, 2004). Depending on the typeface, "x-height" would be 0.6 - 0.8 times of the capital height (Pheasant, 1987). Therefore, more research is needed to determine how VAF responses scale to uppercase and lowercase and how readers adjust the viewing distance when there is a mix, as most text contents are.

Summary

This study demonstrates a productivity improvement when using a large font size compared to smaller font sizes under natural viewing situations for computer users performing visually demanding tasks. The presence of glare led to a reduced the viewing distance. The larger font size of 3.56 mm led to a VAF of 23.4 (VAR = 6.1), which slightly higher than the upper bound of ISO recommendations, while the smallest font size lead to a visual angle of 14.2 arcmin (VAR = 3.7), which was lower than the ISO recommendation. For visually demanding computer tasks, productivity is improved when the font is increased from 2.23 to 3.56 mm. There was significant productivity gain of 3 correct clicks/min and 8% of reduction in perceived task difficulty each 1 mm of font size increase ($p < 0.0001$), which was more pronounced in the young group. Based on the productivity benefit, it is suggested that ISO moved the upper bound of the recommendation (22 arcmin) higher to about 24 arcmin.

Figures and Tables

A.

CKPNA FMD DPK KNOEK KECANBXE ECXR GYD DOAECY SGKDCBX BHD HZN
RBRSB BMKYBNKC CAKPA ABIJAP MCBLYA NODE ESZ ZNZPFD CGIO ALDN
XH BH HXX BPDE EDGBSM YBHP AGRIMI ALHALSA DC CIF GABM NZ OZ
DSK MHMCBLDR RBHBAAPB BEACGPBC CAM LCN NBO OFFJAR CAZGYC COL
SLP GX XSC NCFZZJJ YCX XY YEKAMAS XHOOG ORHP PALSG SAHD DN
PAZ LBF OYFA AOFZRH HOHZOCCZ ZRSZ ZKGD SAGBEX LBNSKG GF FGB
CYC CY XZRLZCXH BRHFMA YGOASA RAYCFMHB BJFZ ZOEPYO FNLA GSOC
DORH FKOMCXE AK KDPDXXAE ESLHY YM NNCZBE RZEASA JNFDZFO OB
FHGOK KOJHYCFO ZRHABCNA CXLZK SAHN AJPCX XPMBYL LGLCA FH HCP
OGEG GOKXAIGE MAGAM IASRXIFY BMKL CFMREBK KYAIAYLG AOBN FEB
CM MCSHIGM EPHC CZSBMB AAP GPSLCC SBGBCCKD DZZBOJMC CBY DPGK
BZCY AACAAZAH HSABXH ICK CBCXZC EIO YMEEENS SCDPCM MLB AE EF
EX XAPADLOY YONL LCPCIOCB BPSO OPRABJS SXDAA HRC BAKAKD DGEF
LM LM OZR HS RCHKCFY SDNASACF CXXLDMAM GBACDCS CMCOR RGD DBA
APE EAF FSCRLBKG GA ACXMEZ OPGBHAO OKS SKFKZBP DNGGB REM NNK
PDBGA AFPK RFKPRZH HCZDXIMG CXKZRA AO AE EZN NKBRRJI HD ABMA

B.

(MNN MMM MNN NMM NNM)(MMN MMM MMN NMM NNM)(MNN NMN NNN MNN MMN)
(NNMN NMNN NNMN NNNN NMMN)(MMN NNN NNN MMN NMM)(NM NN MN NM MN)
(MNM MNM MMN NNM NNM)(NNM NMM NNM MMN NNN)(NMM MNN NMM MMN NNM)
(MNNM NMMM MNNM NNMM MNMN)(NNN NNM NMM NNN MMM)(MN MM NN NN MN)
(MNN NNN NNM MNN NNM)(MMMN MMMN MNNN MMNM MNMN)(MN MN MM MM MM)
(MM MM NN MN NN)(NNM MNN NMN MMM NNM)(MNMM NMMN MMMM MNMM MMNN)
(NN NM MM MM NN)(NMMN NNMN NMMN NNNN MNMN)(MNM MNM NNN MNN NNN)
(NNMN MMMN MNMN NNMN NNMM)(MN MM NM NM MN)(NMM MNN MMM MMN NMM)
(MMNN NMMN MMNN NNMN MNMN)(NMM MMM NNN NNN NMM)(NN NN MM MM MN)
(NMM NMM MNM NMN NNN)(MMMN NNNN NNMM MMMN NMNM)(MN MN NN NM MM)
(MM NM NN NM MM)(NNM MMN MNM NNM MNM)(MNNM MNNM NMMN NMMM MMNM)
(NMM NMN MMM NMM MNN)(MMM MMN NMN NMN MMM)(NNM NNN MMN NNM MNM)
(MMNM NNNN NNMN MMNM MMNN)(MM MN NM MN MM)(NNM MMN NMN MMM NNM)
(MN MN MM NN NM)(MNM NMN MNM NNM MMM)(NNNN MMNN NNNN NMMN MMMM)
(NNM NNM MNM NNN MNN)(NMM MMM NNN NNN NMM)(MNM MMN NNM MMN MNM)
(MNNN NNMM MMMN MNNM MNNN)(MMN MNM NNM MMN MMM)(NN MN MN NN NM)

C.

(MMNMMNM MMNMNMN MMNMMNM MMNNMNN MMNMNMM)(MNM NNN NMM MNM MNN)
(MNM NNM MNM MMM MMM)(NNNMNNM NNNMNNM NNMNMMM NNMNMMM MMMNNMN)
(MNNNMMN MMNNNNN MNNNNNM MNNNMMN NMNNNNM)(MNM NNM MMN MNM NNM)
(MNMNNMM MNMNNMM MMMNNMN NNNNNNN NMMNNNN)(MMN MMN NNM NMN NMM)
(MNM NNM MNN MNN MNM)(NMMNNMM NNMNNMM NMMNNMM NNNMNNN MMMNMNM)
(MMM MMM NMM NNN NNM)(NMNNNMM NMNNNMM NNMNNNM MNMMMMM NNNMMNN)
(MNN NMM NMM MNN MNM)(NNNMMNM NNNMMNM MNNMNNM MNMMMMM MMMNMMN)
(MNNMN MMMNN MMMNM NMMNN MNNMN)(NMNNM NMNNN MNMMM NMNNM NMMMM)
(NNMMNMN MNNNMMM NNNNNMN NNMMNMN NMMMMMN)(NNM NNM NNN NMM NMN)
(NNN MNM NMN NMN NNN)(NNNNNNM MMMNMMN NMMMMNM MMNNNNM NNNNNNM)
(MMNMNMM NNNNMMN MNNNMMM NNNNNMM MMNMNMM)(NMM NNM NMM MNN NMN)
(NNM MNN NMN NMM NNM)(MMMMMNM NNMMMMN MNMMMNN NNMMNMM MMMMMNM)
(MMM MNN MMM MNM NNM)(NNNMMNN MMMNNMN NNMMMNN NNMMNNN NNNMMNN)
(NMMNMMN MMMNNNN NMMNMMN NNMNNMN NNNMNNM)(MNM NMN MNM NMM NNM)
(NMN NNN MNM MNM NMN)(MNNNNNN NMMNMNM MNNNNNN MNNMMNN MMMNMMN)
(MNN NNM MNM MNN NMN)(NNMNMMM MMMMNNM NNNNNNN NNMNMMM NMNMNNM)

Figure 1. Examples of Three Tasks. A. Visual Search Task, B. Abridged MN Task, and C. Hard MN Task. The first MN word after the right parenthesis was the template and subjects had to identify the matching "words" in the row. Each block of text shown occupied approximately 16 cm by 5 cm at the center of the monitor.

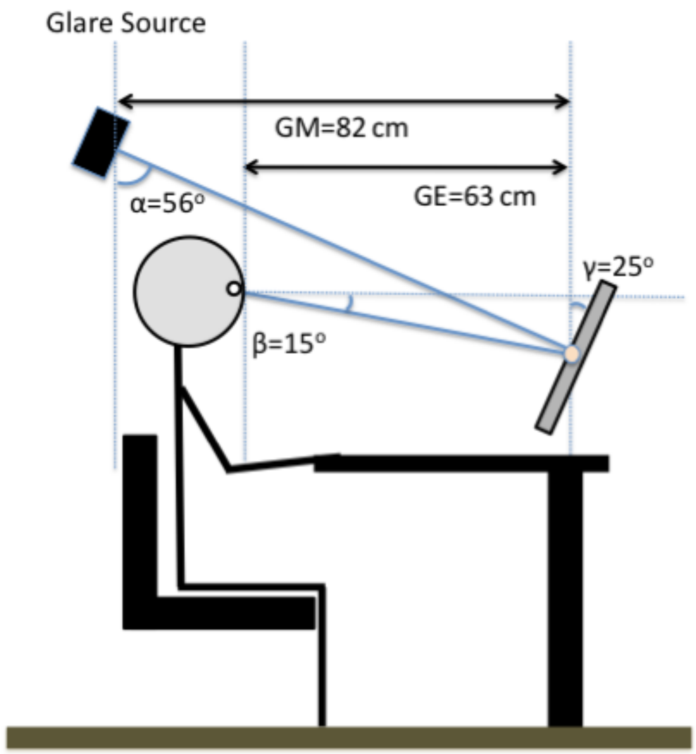


Figure 2. Diagram of the Workstation. The glare source is a LED array. The glare-to-monitor (GM) and glare-to-eye (GE) distances were set while the subject was comfortably reclined in the chair. The slope of the monitor is set to 25 degrees, which located the glare in the center of the monitor as viewed by the subjects. The distance from the monitor to the eye (VD) was calculated using virtual 3D tracking markers at the representative eye point and center of the screen.

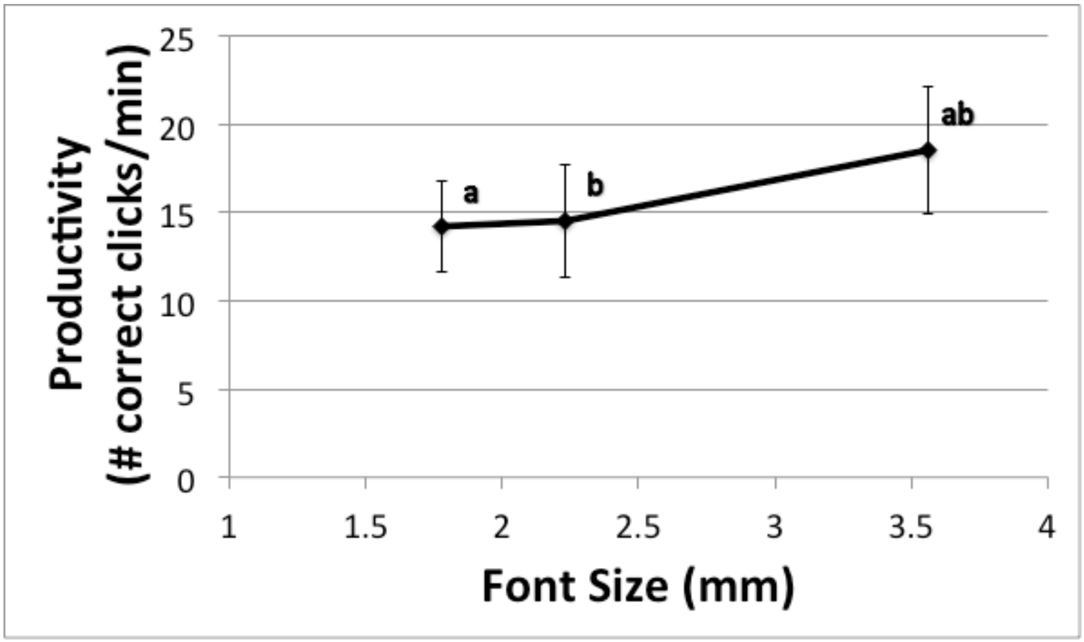


Figure 3. Productivity at the Three Font Sizes. Significant differences between font sizes are indicated with a common superscript.

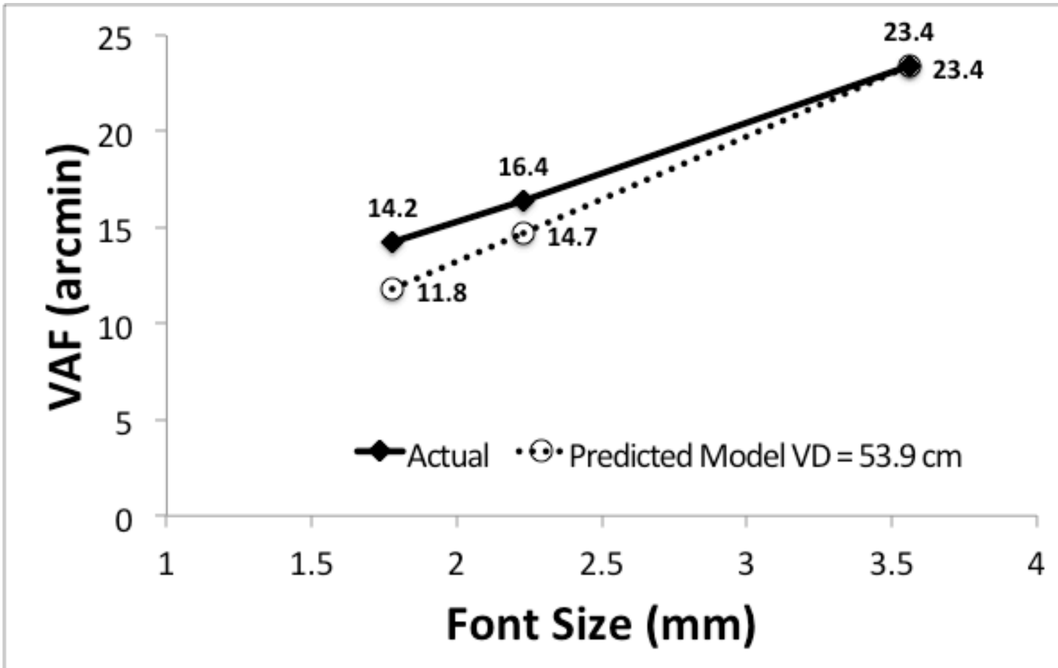


Figure 4. Comparison of the Actual VAFs to the Hypothetical VAFs. The predicted model assumed that the subjects did not reduce the viewing distance at the smaller font conditions

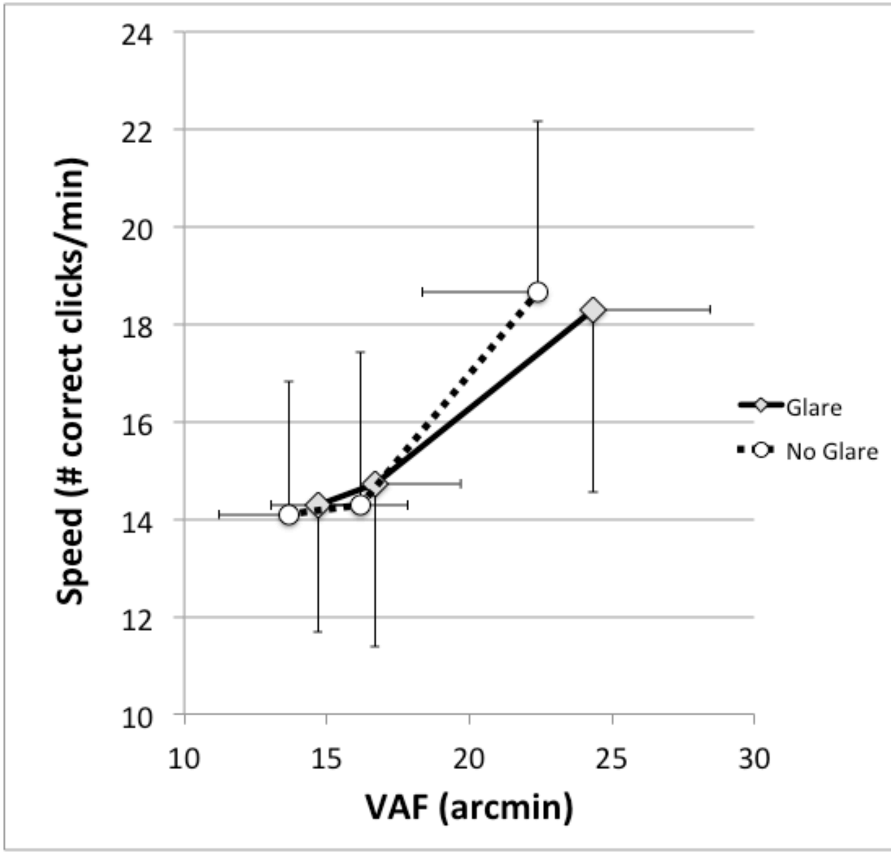


Figure 5. Relationship between Speed and VAF with Data Stratified by the Glare Condition.

Factors	Font Size				Glare		
	Small	Medium	Large	p-value[1]	No Glare	Glare	p-value[1]
Productivity (correct clicks/min)	14.2 (2.6)[a]	14.5 (3.2)[b]	18.5 (3.6)[ab]	< 0.0001	15.7 (3.8)	15.8 (3.7)	0.61
Accuracy (%)	94.6 (4.9)[a]	93.2 (9.3)[b]	97.4 (2.5)[ab]	0.0008	94.7 (8.2)	95.4 (0.04)	0.40
Subjective Rating of Task Difficulty	33.3 (16.1)[ab]	28.8 (17.3)[ac]	19.2 (12.4)[bc]	< 0.0001	26.9 (17.2)	27.2 (15.7)	0.72

[1] RANOVA. Significant differences between test conditions in a row are indicated by common superscripts (Tukey follow-up tests).

Table 1.
Subjective Rating and Performance Measures for Three Font Size and Two Glare Conditions

Factors	Font Size				Glare		
	Small	Medium	Large	*p*-value[1]	No Glare	Glare	*p*-value[1]
Viewing Distance (cm)	44.8 (8.9)[ab]	48.4 (8.9)[ac]	53.9 (9.2)[bc 2]	<0.0001	50.5 (9.9)	47.5 (9.3)	<0.0001
Visual Angle of Font (arcmin)	14.2 (2.9)[ab]	16.4 (3.0)[ac]	23.4 (4.2)[bc]	<0.0001	17.4 (4.9)	18.6 (5.4)	0.0001
Visual Acuity Reserve	3.7 (0.8)[ab]	4.3 (0.8)[ac]	6.1 (1.2)[bc]	<0.0001	4.5 (1.3)	4.8 (1.5)	<0.0001

[1] RANOVA. Significant differences between test conditions in a row are indicated by common superscripts (Tukey follow-up tests).

Table 2
Viewing Distance, VAF, and VAR for Three Font Size and Two Glare Conditions

Dependent Variable	Random-Effect GLM	Font Size (mm)	VAF(arcmin)	VAR
Productivity	R^2	0. 27	0.14	0.30
	Coefficient	2.55*	0.43*	1.67*
		(*p* < 0.0001)	(*p* < 0.0001)	(*p* < 0.0001)
Accuracy	R^2	0.05	< .0001	0.0006
	Coefficient	0.02*	0.001	0.006
		(*p* = 0.001)	(*p* > 0.17)	(*p* = 0.095)
Perceived Task Difficulty	R^2	0.13	0.05	0.03
	Coefficient	-7.75*	-1.18*	-4.45*
		(*p* < .0001)	(*p* < .0001)	(*p* < 0.0001)

Table 3
Random-Effect GLM Results for Three Outcomes Using Font-Related Factors as the Explanatory Variables. Coefficients with a *p*-value less than 0.05 are labeled with a *.

Chapter 4

Effects of Presbyopia, Font Size, and Glare on Symptoms and Postures during Computer Use

Abstract

Objective: This laboratory study examined the effects of presbyopic vision, font size, and screen glare on visual and musculoskeletal symptoms and posture during computer use.
Background: Visual and upper body musculoskeletal symptoms are important health issues for computer users. The roles of font size and computer screen glare on torso and head posture have not been examined in detail. The study findings on productivity have been published.
Method: Nineteen subjects without presbyopia (18-35 years old) and seven subjects with presbyopia wearing bi-/multi-focal/progressive reading glasses (55-65 years old) participated in this full-factorial study with two trial factors: font size and reflective glare. The three font size heights were 1.78, 2.23, and 3.56 mm and the screen glare condition was present or absent. The monitor location was fixed but subjects were allowed to move their body and the chair as they desired. Subjects performed visually demanding tasks on the computer while posture was recorded. Visual and upper body symptoms were recorded after each task.
Results: Presbyopic group had 15.87 deg larger head angle than the younger group ($p < 0.0001$); they also had higher neck and shoulder discomfort. There was no significant difference between these two groups for other postural angles or distance measures. Only font size had an effect on visual discomfort ($p < 0.0001$); reducing font size from 3.56 mm to 1.78 mm caused 8.9/100 or 48% increase in visual symptom rating. For every 1 mm increase in font height, there was 40.63 mm ($p < 0.0001$), 4.54 mm ($p = 0.045$), and 3.48 mm ($p < 0.0001$) forward change for torso-to-monitor distance (*dTD*), chair-to-monitor distance (*dCD*), and head forward distance (*dHF*), respectively. Torso flexion, chair reposition, and head forward contributed to 77.8 %, 4.3 %, and 2.7 % of the reduction in viewing distance, respectively, across the font size conditions. When the glare was present, head forward distance did not increase, but torso moved forward 27.65 mm ($p < 0.0001$) and head moved to the side by 8.83 mm ($p = 0.023$).
Conclusions: As the font size became smaller, subjects reduced the viewing distance more by leaning forward than by moving the chair forward. The relative contributions of each of the three components investigated were about the same for both groups. Reflective glare induced non-neutral posture including neck flexion, torso forward, and head movement to the side.
Application: The findings can provide guidance for selecting font size and eliminating screen glare in order to avoid forward leaning postures when performing visually intensive tasks on the computer.

Introduction

A shift from manufacturing industries to service and information industries has resulted in an increase in computer use at work. According to 2003 US Census Bureau's Current Population Survey (CPS) data, 56% adults used computer at work (Day, 2005). Despite the usefulness of computers, this stationary work in the modern workplace has led to musculoskeletal symptoms and disorders as well as to visual symptoms, which are recognized by World Health Organization as major occupational health concerns (WHO, 1998). These adverse health outcomes could be reduced through work organizational changes.For example, providing ergonomics training, redesigning equipment and modifying other aspects of the environment such as adjustable workstations could encourage proper postures (WHO, 1998).

High prevalence and incidence of neck/shoulder musculoskeletal symptoms have been reported by computer office workers from a wide range of occupations. Using a validated upper extremity questionnaire to study the prevalence of symptoms among 282 computer office workers at a mobile telecommunication company and at three banks in Khartoum, Sudan, they found that 67% and 41% of the subjects had more than one week of neck and shoulder complaints in the past 12 months, respectively (Eltayeb, Staal et al., 2008). Another cross-sectional study in Germany reported a 55% and 38% one-year prevalence of neck and shoulder pain, respectively (Klussmann et al., 2008). In one 10-month prospective study, the incidence rate is as high as 67 cases per 100 person-years for pain (>= 3days) in the neck region and 41 cases for the shoulder region (Tornqvist et al., 2009). In another 3-year prospective study that exclusively follows healthy and relatively new workers, there were 58 new cases of neck/shoulder symptoms and 35 cases of neck/shoulder musculoskeletal disorders per 100 person-years (Gerr et al., 2002). Sustained posture has been identified as an important risk factor for neck/shoulder musculoskeletal symptoms (Fernandez-de-las-Penas, Alonso-Blanco, Cuadrado, Gerwin, et al., 2006; Hagg & Suurkula, 1991; Treaster et al., 2006).

With higher resolution computer monitors, the default font size of common programs can be hard to read, particularly when the monitor is placed at a relatively far viewing distance. Multiple psychophysical studies have shown that larger font size is associated with faster reading speeds (Lee et al., 2008; Legge et al., 1985; Legge & Bigelow, 2011; Levi, 2008; Levi & Carney, 2009; Whitney & Levi, 2011; Whittaker & Lovie-Kitchin, 1993). To reduce the viewing distance, a computer user could lean forward or move the head forward instead of moving the seat forward since the adjustment is subtle. Leaning forward through neck and/or torso flexion increases the biomechanical load of the upper trapezius, the posterior cervical and the suboccipital muscles such as the levator scapulae, which have important postural function for office work (Bennett, 2007). Forwarded head posture increases the cervical muscle activities and consequently increases the muscle strain. If the non-neutral posture is maintained, sustained muscle contraction will reduce the local oxygen supply, lead to the sensitization of pain receptors, and ultimately cause neck/shoulder pain (Treaster et al., 2006). Computer users could also increase the font size, but this is usually not done.

In addition to computer settings, non-robust visual functions can affect an individual's preferred/habitual viewing distance. The visual condition, uncorrected defocus at closer distances, is more likely to be a concern for office workers older than 40 because of the progression of presbyopia. Presbyopia is the stiffening of the lens of the eye with age, which leads to an inability to adjust focus (i.e. to accommodate) (Fisher, 1973; Glasser & Campbell, 1998; Schachar, 2006). Typically, presbyopia manifests as a reduced ability to focus on near objects, but, if uncorrected, it also leads to a limitation in the range of viewing distances and a compromised visual acuity. Presbyopia is a progressive condition and some people have not been aware of how their vision is changing and how it is affecting their posture.

Presbyopia is present in almost all people over 40 years old; most people over 48 can focus only on distances beyond 40cm and completely lose the ability to accommodate after the age of 55 (Sun et al., 1988). In such cases, proper visual aid is required for near work. The amount of visual correction needed also depends on an individual's pre-existing refractive error. On the other hand, one can have reduced convergence ability at near distances due to convergence insufficiency, which has a prevalence of 3-5% yet is under-referred and often remains untreated (Scheiman et al., 2005). People with these two conditions would prefer longer viewing distances to alleviate the visual demands of near work. Therefore, there is a potential trade-off between the opposing needs of vision: while it is desired to have larger VAR, there is a constraint to stay further away from the monitor. It has been suggested that, without adjusting the default out-of-box font size, the VAF approaches the acuity reserve, which then induces forward head posture, neck flexion or extension and thoracic spine flexion and ultimately lead to neck/shoulder symptoms (Rempel, 2007). If the font size is not increased accordingly, a forward head posture will be adopted when the VAR is low, leading to increased cervical muscle strain and the compression of cervical tissues.

Reflections on a computer screen, which can be characterized as image glare, can reduce target image contrast and can lead to visual distractions and to focus shifts between the task and the distant light source. The glare may be localized on the screen (area glare), or a uniform glare may be spread evenly over the whole screen surface. Often, these reflections are not immediately noticed. However, if the glare is strong or localized, it may be disabling (e.g. it may reduce visual acuity) or induce discomfort (Sheedy et al., 2005). Therefore, lighting in the office is an important environmental factor. In the workplace, reflective glare resulting from nearby light sources reflecting off the monitor is one of the most frequent complaints related to computer use (Bernecker et al., 1993; North, 1991). The eye-screen geometry determines the offending zone of the light source, which may be located on the ceiling, plane, a wall, or a partition. When it is not easy to change the light sources, one may adjust the posture rather than the workstation to change the eye-screen geometry.

Viewing distance and viewing angle (vertical or lateral) are common variables reported as predictors for symptoms in office ergonomic studies. However, they typically can be changed through a combination of postural adjustments and chair position changes. While the former, if sustained for a prolonged period of time, can lead to musculoskeletal discomfort or even disorder, the latter will not. Therefore, it is important to determine, when given the choice, whether posture change is a more common approach to changing viewing distances as compared to seating position adjustments. This can be determined by comparing the proportions of distance changes due to postural changes with that of those due to chair translation.

The purpose of this paper is to investigate the effects of font size and reflective glare on visual and musculoskeletal symptoms and on the postures of users of different ages (i.e. without presbyopia vs. with presbyopia) during the performance of visually demanding computer tasks. The independent effects and the interactions of presbyopia, font size, and glare on visual and physical discomfort, posture angles and distances were investigated. While the monitor was fixed after adjusting for the subjects' anthropometry and viewing angle, the subjects were able to freely move their upper body and the chair. Therefore, the results will offer insights into actual behaviors at work and can be extrapolated to real world situations. The practical implication of the findings will be to recommend font sizes and viewing distances that could prevent symptoms related to computer work.

Method

Participants and Experimental Design

The method in this study was similar to the one described in the previous chapter. Nineteen young (18-35 year-old) and seven elder presbypoic (55-65 year-old) subjects participated in this full-factorial, repeated measures study with two trial factors: font size and reflective glare. Performance at three different visual tasks (one visual search task and two matching and selection tasks with different memory demands) was measured for texts of three sizes in both the presence and absence of glare. Subjects performed visually demanding tasks that required similar visual skills to common tasks such as Internet use, data entry, or word processing. The three font sizes of Arial type had capital letter heights of 1.78, 2.23, and 3.56 mm. The glare was created by a LED worklight reflected of the matte computer monitor. The monitor location was fixed but subjects were allowed to move their bodies and the chair.

Outcome Measures

There are three categories of outcomes that we measured to understand the possible health effects of presbyopia, font size, and glare; they are illustrated in Figure 1: (1) pre-post task differences of discomfort ratings for five regions (eyes, neck, shoulders, upper back, and lower back) using a visual analogue scale slider displayed on the screen with verbal anchors "None" and "Severe" on either end of the scale, (2) posture angles, and (3) distance measures related to postures including head side translation measured as the Y-direction offset of the representative point of the eyes (i.e. the point on the ridge just above the nose between the two eyes) to the center of the monitor (HST, not shown in the figure along the Y axis). The posture angles and distance measurements were obtained through processing motion capture data with continuous recording at 30 Hz using a 3D motion capture system with two monitor banks (OptoTrak 3020, Northern Digital, Ontario, Canada). Three infrared emitting diodes (IREDs) on a rigid body were secured (i.e. triads) to form virtual markers for angle and distance calculations. The triads on the top of the monitor, just anterior to the subjects' tragus, on the sternum, and on the top of the chair were used to identify the center of the monitor, the representative point of the eyes, C7, and the chair top/seat, respectively.

We also looked into the amount of the contribution that postural change (torso and head) and chair reposition to the reduced viewing distance by computing the changes in these measures during the three font size conditions compared to that of the reference measures obtained from the average of three baseline conditions. The baseline condition was a 5-min baseline trial (large font size, basic visual search task, no glare) at the beginning of each experiment block. The absolute changes and proportions of changes in the sagittal axis in viewing distance changes (dVDx) through torso (dTD), chair (dCD) and head forward (dHF) adjustments under three font size conditions were reported.

Statistical Analysis

Differences among the factor levels for all outcome measures were initially evaluated by repeated measures ANOVA (RANOVA) using *PROC GLM* command in SAS 9.0 with presbyopic status as a grouping factor and font and glare as trial factors modeled with two-way interaction terms between these factors. Interaction terms between presbyopia, font and glare were not significant after correcting for multiple comparisons. Presbyopic factor had no significant effect in the models so it was removed from subsequent models. Factors with significant F tests for fixed effects were followed up with Tukey's multiple comparisons. In the above models, font size is treated as a categorical variable. To investigate the effects of font size as a continuous variable and the dichotomous presbyopic status and glare variable on the distance outcomes, a random effects general linear model was used to evaluate the independent effects of font and glare and their interaction (*xtreg* command, account for repeated measures; STATA 10).

Results

The outcome measures for the three factors investigated, presbyopia, font size and glare, are listed in Tables 1,2, and 3. When there were no significant effects of the factors, the overall means of those outcome measures were reported as well (Table 1 and Table 3). The overall viewing distance was 490.27 (SD = 96.86) mm, torso-to-monitor distance in x-direction was 554.85 (SD = 80.60) mm, and head forward distance in x-direction was 197.18 (SD = 33.20) mm.

Factors' Independent Effects on Symptoms and Postures

In addition to higher baseline symptoms (*Neck* (P/NP): 6.25(5.20)/0.51(0.88), $p = 0.017$; *Shoulder* (P/NP): 5.25(4.33)/0.47(0.92), $p = 0.017$; in contrast to *Eyes* (P/NP): 6.87(6.70)/7.23(8.67), $p = 0.091$), elder/presbyopic subjects had higher pre-post task differences in symptom ratings for neck (14.55/100 or 4.6X higher, $p = 0.0014$) and shoulders (11.30/100 or 5.1X higher) as listed in Table 1. They also had larger head angle (120.73 (SD = 6.93) deg) compared to the young subjects (104.86 (SD = 5.85) deg) ($p < 0.0001$) as expected from limited field of view of the near zone on the bi- or multi-focal glasses (Table 1).

Font size had significant effects on eight outcome measures (Table 2). Among the three factors investigated, only font size had small but significant effect on visual symptoms, which were significantly different for 0.1, 0.2, or 0.3 log units change in font size: 3.5/100 or 13.4% higher for the medium font compared to the small font, 5.65/100 or 30% for the medium font compared to the large font, and 8.9/100 or 47.9% for the medium font compared to the large font ($p < 0.0001$). Neck symptom rating was less sensitive to font size changes (2.50/100 or 41.0% for M compared to L, $p = 0.0056$). The posture and distance results indicated that, as the font size became smaller, subjects reduced the viewing distance, mostly by leaning forward, and as a consequence, head extension (HA), neck flexion (NF-V), torso flexion (TF-V), and thoracic flexion (TNxz) angles increased. Even though the significance level was borderline before the Bonferroni adjustment and not significant using the adjustment criterion, the head forward distance increased as a response to 0.3 log units of fonts size change from 3.56 mm to 1.78 mm.

As shown in Table 3, subjects had slightly higher pre-post task neck symptoms in the glare condition (1.3/100 or 19.1%, $p = 0.0022$). With the presence of glare, subjects had small but significant larger NF-V, TF-V, smaller TNxz, VD, and TD. The effects were all smaller than that induced by decreasing font size. In our experiment setup, this forward action would not produce much more benefit of removing glare from the task area; but it may have the benefit of increasing font size for compensating the contrast reduction due to reflective glare. Increased head side translation of 8.83 mm ($p = 0.023$) with borderline significance could possibly serve to remove the reflective glare from parts of the task area.

Postural Change Strategy to Reduce Viewing Distance

In the experiment conditions, where the overall task difficulty was higher and glare could be present, small font size induced largest viewing distance change along the X-axis (204.22 mm) while the changes were smaller for the medium and large font size conditions (168.37 mm and 110.68 mm respectively). On the other hand, there were about 2 cm dVDx that was not explained by the three components there and could be the shifting in one's hip relative to the chair top that was unable to be captured by the experiment setup due to the limited field of view of the motion capture cameras (Table 4a). Even though the reduction in the viewing distance changes decreased with font size increase, the relative contributions of each of the three components investigated were about the same. Torso flexion, chair reposition, and head forward contributed to 77.8 %, 4.3%, and 2.7 % of the reduction in viewing distance, respectively, across the font size conditions (Figure 2).

General linear models were used to explore the relationships between the three factors, i.e. presbyopic status (*PNP*), font size (*Fontheight*), reflective glare (*Glare),* and the four distance outcome measures. Even though the R^2 were small, font size had significant beta coefficients for three forward distance measures while the other two factors were adjusted for: for every 1 mm increase in *Fontheight*, there was 40.63 mm ($p < 0.0001$), 4.54 mm ($p = 0.045$), and 3.48 mm ($p < 0.0001$) forward change for *dTD*, *dCD*, and *dHF*, respectively. When the reflective glare was present, torso moved forward 27.65 mm ($p < 0.0001$) and head to the side for 9.28 mm ($p < 0.0001$). Presbyopic vision did not affect one's posture response to perform visually demanding tasks.

Conclusions and Discussion

This study demonstrates the benefits (lower visual and neck discomfort and more neutral postures) of using a larger font size while performing visually demanding tasks naturally. Postural change contributed more to viewing distance reduction than chair positioning. Reflective glare was correlated with higher neck symptom and non-neutral head posture.

Visual Symptoms

In this study, we evaluated the effect of different visual demands on musculoskeletal symptoms in a more natural working situation where the subjects could freely adjust their chair positions and postures. Surprisingly, though we found that visual symptoms were negatively affected by the font size, presbyopia and glare had no effect. It should be pointed out that presbyopia and glare were found to be effective in other studies, and glare was expected to produce visual discomfort in older subjects (Bailey & Billmore, 1991; Sheedy, 2005). Our finding may be due to postural changes, such as moving one's head to the side; thus, subjects could have mitigated the glare in our study. We also found that a small difference in font size (as small as 0.1 log unit, which is equivalent to one row on a visual acuity chart) triggered a small but significant difference in visual discomfort within less than a half-hour of performing visually demanding tasks. It could be attributed to the increase in oculomotor demands (more precise focus and fixation, higher accommodation, and convergence performance).

Neck and Shoulder Symptoms

All three factors had significant effect on neck symptom ratings: the presbyopic group had a 14.55/100 higher rating than that of the younger group, which was most pronounced and may have been an age effect mediated through the larger head angle; the difference in head angle between young and presbyopic subjects was most likely because the latter group wore bifocal or multifocal glasses.

Medium font size as well as glare conditions both induced worse neck symptoms. Medium font size induced 2.5/100 higher neck symptoms compared to the large font size condition, whereas subjects had 1.3/100 higher neck symptoms in the glare condition compared to the no-glare condition. These effects may have been due to increased demands for attention when the visual target was harder to discern. It has also been shown that in an office setting, visual symptoms are highly associated with physical symptoms, suggesting that visual demands could result in physical pains (Hayes, Sheedy, Stelmack, & Heaney, 2007). The connection between visual demand and musculoskeletal symptoms was further established by laboratory studies. For instance, after a 30-minute typing task with increased visual stress from reduced visibility of the transcribed texts on the computer, subjects had higher trigger point sensitivity (an indication of muscle pain) and reduced electromyography (EMG) cycling frequencies in the neck/shoulder regions (Treaster et al. 2006). Another study reported that adding attention-related activities to a computer task increased EMG activity, particularly in the upper trapezius muscles (Lundberg et al., 1994; Waersted & Westgaard, 1996).

We observed neck and sometimes shoulder symptoms associated with increasing visual demands (reduced font size or reflective glare). Even though the effects reported in our study were small due to the short time of each task (~20 minutes), they could have been aggravated if the work duration had been longer. Our findings also suggest that reducing visual demands of computer work by increasing font size and reducing glare may reduce neck/shoulder musculoskeletal symptoms at work. An example that supports this rationale is a 6-month prospective, parallel group, intervention study on male computer workers where the control group had significantly higher neck and shoulder self-rated pain score compared to the groups that received optometric correction intervention (Aaras, Horgen, Bjorset, Ro, & Thoresen, 1998).

Physical Symptoms and Posture

Head posture may play an important role in the development of neck symptoms by increasing the load of the cervical muscles. Several laboratory studies have provided consistent evidence for an increase in cervical erector spinae muscle activity with increased head flexion (Sommerich, Joines, & Psihogios, 2001; Straker, Skoss, Burnett, & Burgess-Limerick, 2009). Based on the biomechanical model built with experimental kinematic data, the predicted muscle strain presents a roughly linear relationship with the head flexion angle (Straker et al., 2008). Even though the quantitative effects of head/neck postures on other cervical muscles were less clear, our data on neck symptoms generally agreed with the posture data. We found that head postures always changed significantly when neck symptoms worsened. Presbyopic subjects tilted their heads backward more than nonpresbyopic subjects. Glare conditions induced more lateral head translation. Font size affected forward translations of both head and torso.

With a head forward posture, the neck muscles hyperextend and the total load on all muscles supporting the head increases, approximately twofold load for every inch the head goes forward. The regression model reported that font size was correlated with the head forward distance ($p < 0.0001$). This validated the health concern that these two factors may contribute to prevalent neck pain in the workplace and may serve as intervention points. The regression model also indicated that subjects on average moved their heads to the side for 9.28 mm ($p < 0.0001$), indicating this amount of reflective glare can also lead to subtle changes in posture intended to modify the eye-monitor-glare geometry. This asymmetric, non-neutral posture may lead to neck/shoulder symptoms for a longer exposure time like the head flexion/extension as well.

Postural Change Behavior

This is, to our knowledge, the first quantitative report on postural change strategy of computer users. Even though the reduction of the viewing distance decreased with increases in font size, the relative contributions of each of the three components investigated remained constant: torso flexion, chair reposition, and head forward contributed to 77.8%, 4.3%, and 2.7% of the reduction in viewing distance, respectively. This suggests that computer users mostly rely on posture to adjust their viewing distance during work, even though they have the option to move the chair. This highlights the importance of being aware of posture and of factors (e.g., font size and reflective glare) that prompt forward posture; posture awareness and posture readjustment can reduce discomfort and the likelihood of musculoskeletal disorders. Sustained posture induces symptoms possibly through the development of trigger points, which are hyperirritable spots in skeletal muscles that are often diagnosed with palpable tender nodules in taut bands of muscles that produce recognizable and predicted pain referral patterns (Fernandez-de-las-Penas, Alonso-Blanco, Cuadrado, & Pareja, 2006; Hagg & Suurkula, 1991; Tough, White, Richards, & Campbell, 2007; Treaster et al., 2006).

Our results also led us to hypothesize that with increasing visual demands, subjects changed their postures to lessen the visual symptoms but at the same time exacerbated their musculoskeletal symptoms. In effect, visual problems were traded for musculoskeletal problems, similar to the tradeoffs found in monitor placement height. Studies have shown that the monitor height affects postures, thus causing musculoskeletal symptoms(Burgess-Limerick, 1999; Sommerich et al., 2001). Sommerich et al. (2001) proposed a tradeoff model between musculoskeletal strain and visual strain when selecting monitor heights. When the monitor was placed higher, subjects assumed a more upright posture with less neck flexion and, therefore, reduced the strain on the neck muscles (Straker et al., 2009). Similarly, we found that the postures changes observed in this study could decrease the impact of the visual demands, thus lessening the visual symptoms. As the glare was most strongly illuminated in the center of the monitor, lateral head translations were predicted to reduce their negative impact. Forward postures decreased the viewing distances and partially compensated for smaller font sizes. Taken together, it seems that people may subconsciously adopt suboptimal postures in order to optimize visual experience and performance.

Limitations of the Study

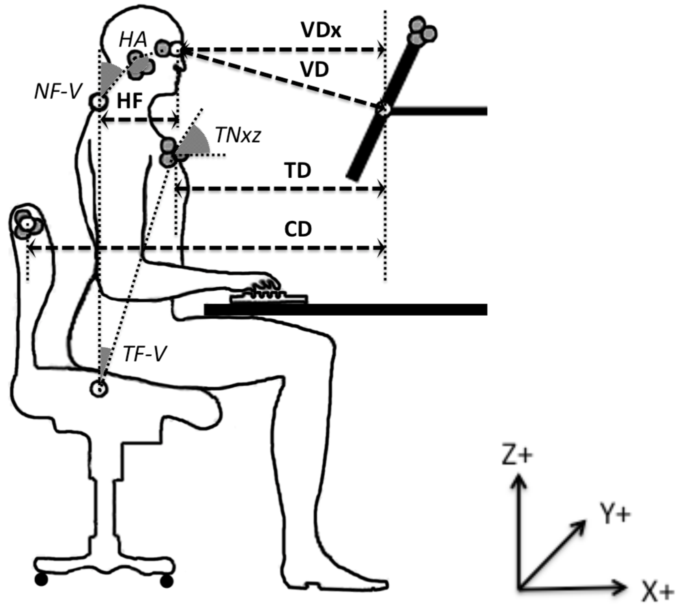
More severe neck and shoulder pains were reported by presbyopia subjects. However, the age effect on musculoskeletal symptoms has been reported in field studies (Tornqvist et al., 2009) and elevated muscle activities in the neck/shoulder regions were reported for the older group (Alkjaer, Pilegaard, Bakke, & Jensen, 2005; Laursen & Jensen, 2000). Therefore, it is difficult to discern the effect of age and presbyopia. Another limitation of the study is that we only had one level of reflective glare, and therefore the findings may not be able to be applied broadly. Nevertheless, this is the first study that reported on the effect of reflective glare on computer users' symptoms and postures.

Summary

There was no significant difference between presbyopic and nonpresbyopic subjects for the postural distance measures. The posture distance results indicated that, as the font size became smaller, subjects reduced the viewing distance by leaning forward and not so much by moving the chair forward. Even though the reduction in the viewing distance changes decreased with font size increase, the relative contributions of each of the three components investigated remained constant. The regression model indicated that head forward distance increased as the font size decreased but not with glare. The head moved to the side and the torso moved forward when glare was present.

Figures and Tables

A.



B.

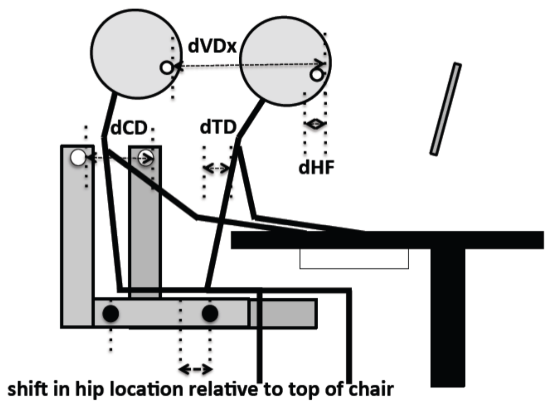


Figure 1. Markers and Distance Measures. Markers (gray: real markers, white: virtual markers) and distance measures, including: A. Diagonal Viewing Distance (VD), Horizontal Viewing Distance (VDx), Horizontal Torso-to-Monitor Distance (TD), Horizontal Canthus-to-C7 or Head Forward and Distance (HF), Horizontal Chair-to-Monitor Distance (CD), Head side translation (HST) is not shown in the figure because it is along the Y-axis. B. The absolute changes in the sagittal axis in viewing distance changes (dVDx) through torso (dTD), chair (dCD) and head forward (dHF).

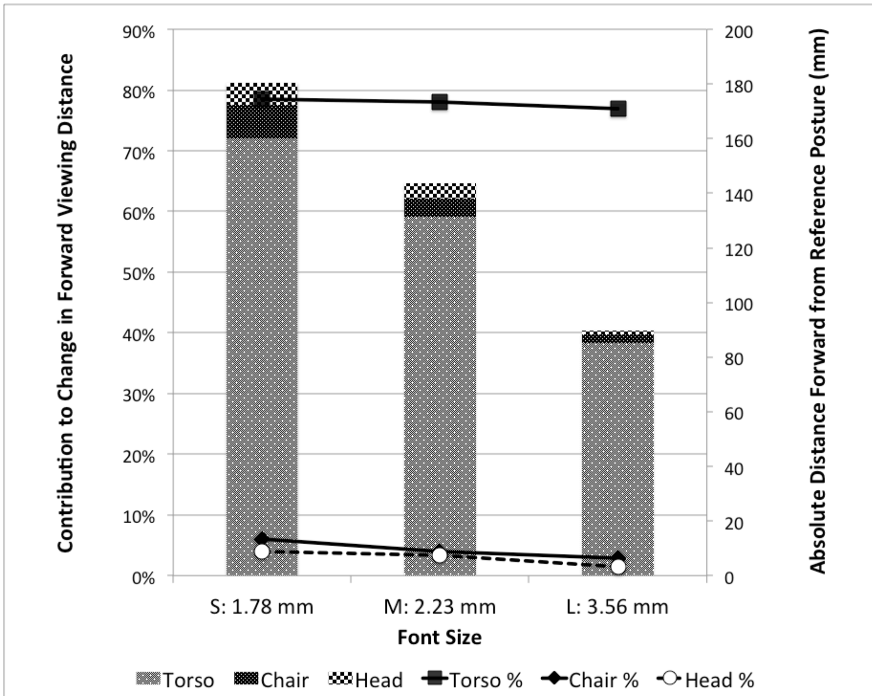


Figure 2. Elements Contributed to Viewing Distance Changes. Absolute changes (illustrated by stacked bars) and proportions of changes (illustrated by lines) in viewing distance changes from the baseline through torso (dTD), chair (dCD), and head forward (dHF) adjustments given three font sizes.

Outcome Measure	Non-Presbyopic	Presbyopic	*p-value*
	Pre-Post Task Symptoms		
Visual Symptoms	23.89 (16.93)	22.38 (11.10)	0.80
Neck Symptoms	3.14 (4.42)	17.69 (13.15)	0.0014*
Shoulder Symptoms	2.20 (3.61)	13.5 (10.99)	0.0024*
Upper Back Symptoms	1.18 (2.18)	4.40 (8.27)	0.11
Lower Back Symptoms	2.83 (4.53)	4.76 (8.42)	0.43
	Posture Angles		
HA (deg)	104.86 (5.85)	120.73 (6.93)	< 0.0001*
NF-V (deg)	52.70 (11.40)	53.76 (5.22)	0.80
TF-V (deg)	17.63 (9.18)	16.59 (6.52)	0.68
TNxz (deg)	18.63 (11.73)	24.99 (7.77)	0.14
	Distances		
VD (mm)	473.90 (103.19)	529.15 (65.92)	0.12
TD (mm)	550.58 (86.05)	565.00 (65.59)	0.63
HF (mm)	199.32 (37.69)	192.10 (17.98)	0.61
HST (mm)	-28.25 (34.61)	-30.45 (30.52)	0.87

Table 1.
Independent Effects of Presbyopia on Outcome Measures.
HA: head angle, formed by the canthus-tragus line and tragus-C7 line; NF-V: neck flexion angle with respect to vertical, TF-V: torso flexion angle in respect to vertical; TNxz: thoracic flexion angle as indicated by the marker triad placed on the sternum; VD: diagonal viewing distance; TD: X-direction torso-to-monitor distance; HF: X-direction canthus-to-C7, or head forward and distance; HST: head side translation. Significant differences between the condition are labeled with a * (RANOVA).

	Small (1.78mm)	Medium (2.23mm)	Large (3.56mm)	*p-value*
		Pre-Post Task Symptoms		
Visual Symptoms	27.49 (15.53)[ab]	24.24 (16.15)[ac]	18.59 (13.38)[bc]	< 0.0001*
Neck Symptoms	7.64 (11.31)	8.60 (10.80)[a]	6.10 (9.07)[a]	0.0056*
Shoulder Symptoms	5.32 (8.21)	6.10 (8.58)	5.22 (8.65)	0.39
Upper Back Symptoms	2.36 (5.99)	2.12 (4.51)	1.92 (4.60)	0.28
Lower Back Symptoms	3.53 (6.40)	3.24 (5.98)	3.43 (5.68)	0.44
		Posture Angles		
HA (deg)	108.79 (9.90)[ab]	109.73 (9.63)[a]	110.15 (9.18)[b]	0.0054*
NF-V (deg)	55.65 (9.97)[ab]	53.54 (9.45)[ac]	49.84 (9.77)[bc]	< 0.0001*
TF-V (deg)	20.02 (7.01)[a]	18.43 (9.30)[b]	13.52 (7.68)[ab]	< 0.0001*
TNxz (deg)	17.67 (9.56)[a]	19.80 (10.11)[b]	24.07 (12.54)[ab]	< 0.0001*
		Distances		
VD (mm)	448.38 (88.91)[ab]	483.58 (88.60)[ac]	538.89 (92.25)[bc]	< 0.0001*
TD (mm)	520.25 (71.80)[ab]	548.98 (75.50)[ac]	595.33 (77.17)[bc]	< 0.0001*
HF (mm)	200.09 (32.67)[a]	197.76 (35.88)	193.69 (31.19)[a]	0.05*
HST (mm)	-28.89 (35.44)	-30.52 (31.86)	-27.33 (33.26)	0.62

Table 2.
Effects of Font Size on Outcome Measures. See Table 1 for acronyms. Significant differences between the condition are labeled with a * (RANOVA). Based on Tukey follow-up tests, significant differences using the alpha of 0.05 between test conditions in a row are indicated by common superscripts.

	No-Glare	Glare	*p-value*
	Pre-Post Task Symptoms		
Visual Symptoms	23.22 (15.57)	23.66 (15.36)	0.57
Neck Symptoms	6.80 (9.70)	8.10 (11.13)	0.0022*
Shoulder Symptoms	5.35 (8.47)	5.74 (8.45)	0.80
Upper Back Symptoms	2.12 (5.43)	2.15 (4.68)	0.41
Lower Back Symptoms	3.33 (5.98)	3.47 (6.04)	0.34
	Posture Angles		
HA (deg)	109.44 (9.44)	109.68 (9.68)	0.72
NF-V (deg)	52.15(10.29)	53.88 (9.62)	0.0006*
TF-V (deg)	15.81 (7.30)	18.84 (9.30)	< 0.0001*
TNxz (deg)	21.65 (10.99)	19.38 (11.11)	0.0052*
	Distances		
VD (mm)	505.10 (99.13)	475.44 (92.80)	0.0002*
TD (mm)	568.67 (81.65)	541.03 (77.60)	0.0001*
HF (mm)	196.51 (32.00)	197.85 (34.54)	0.54
HST (mm)	-24.73 (29.66)	-33.56 (36.30)	0.023

Table 3.
Effects of Glare on Outcome Measures. See Table 1 for acronyms. Significant differences between the condition are labeled with a * (RANOVA).

Font Size	1.78 mm	2.23 mm	3.56 mm
dTD (mm)	160.20 (70.88)	131.47 (76.70)	85.12 (75.43)
dCD (mm)	12.22 (52.43)	6.64 (57.28)	3.17 (49.08)
dHF (mm)	7.96 (13.29)	5.63 (11.46)	1.56 (7.92)
Sum (mm)	180.38	143.74	89.85
dVDx (mm)	204.22 (86.90)	168.37 (92.12)	110.68 (91.13)
Difference (mm)	20.84	24.63	20.83

Table 4.
Elements Contributed to Viewing Distance Changes.
Along the sagittal axis, the absolute changes of changes in horizontal viewing distance changes toward the monitor (dVDx) through torso (dTD), chair (dCD), and head forward (dHF) adjustments given three font sizes.

	dTD	dCD	dHF	HST
Overall R^2	0.20	0.07	0.11	0.02
Coef. PNP	26.67 ($p = 0.35$)	29.34 ($p = 0.153$)	-5.59 ($p = 0.093$)	-2.18 ($p = 0.87$)
Coef. Fontheight	40.63 ($p < 0.0001$)*	4.54 ($p = 0.045$)*	-3.48 ($p < 0.0001$)*	1.22 ($p = 0.45$)
Coef. Glare	-27.65 ($p < 0.0001$)*	-3.14 ($p = 0.331$)	1.34 ($p = 0.30$)	-9.28 ($p < 0.0001$)*

Note: dTD, dCD: (+) away from the monitor; dHF: (+) towards the monitor; HST: (-) means more off center/to the right

Table 5.
Overall R^2 and Coefficients of All Three Factors in the General Linear Model with dTD, dCD, dHF and HST as the Outcome Measures.

Chapter 5

Conclusions and Future Studies

Summary

The purpose of this dissertation was to quantify the effects of individual (binocular vision function, presbyopia) and environmental (visual demands, font size, glare) factors on the visual and physical symptoms, productivity, and postures of the computer users in a well-controlled laboratory environment. The first study focused on examining the effects of accommodative and vergence demands imposed by viewing distance or optical lenses/prisms on the visual system. The second study focused on how individuals of different ages responded to a range of font sizes and reflective glare. These are, to our knowledge, the first quantitative reports on the development and retention of symptoms for various oculomotor demands, effects of reflective glare off a monitor, and postural change behaviors of computer users under a free-viewing setting in a laboratory.

By quantifying the effects of combinations of oculomotor demand and the individual's binocular function (specifically divergence limit) on the development and persistence of symptoms, along with the objectively measured visual function changes after a 2-hour visually demanding task, Chapter 2 demonstrates that when the demands were specified by the viewing distance only, the symptom changes were similar for the near (33 cm) and far (100 cm) conditions for young subjects with robust accommodation and binocular vision. When the demands were modified by lenses or prisms, a decrease in 1 D accommodative demand at near distance produced a slightly larger post-task increase ($p = 0.014$) and longer retention ($p = 0.0005$) of eye strain compared to viewing naturally at 33 cm or a decrease in 6 PD convergence demand at the same viewing distance. However, the manipulation of the accommodative demand did not have effects on the symptom recovery at the 100 cm viewing distance. The static accommodation amplitude at far distance was 0.17 D larger ($p = 0.038$), and the dynamic divergence response amplitude was 0.92 PD smaller ($p = 0.030$) in the near viewing distance condition compared to the far viewing distance condition, indicating that there were visual functional indications for excess oculomotor exertion, despite the fact that there was no symptom onset. Based on a general linear regression model, subjects' divergence limits had a small but significant effect on the symptom, eyestrain ($p = 0.001$). All together, there was no evidence that additional lenses or prisms to reduce the oculomotor demands would have helped to prevent visual symptoms for young computer users. There was some suggestion that prolonged computer work at very close viewing distance (33 cm) may lead to accommodative spasm and reduced the ability to diverge, which could cause blurred vision.

Chapter 3 presents the first part of the full-factorial, repeated measure study, which examined the effects of presbyopia, font size, and reflective glare on the visual performance of 19 young and 7 older/presbyopic subjects. Results showed a productivity improvement when using a large font size (3.56 mm, average visual angle 23.4 arcmin) compared to smaller font sizes (1.78 mm or 2.56 mm, average visual angles 14.2 or 16.4 arcmin) for computer users performing visually demanding tasks where they could freely adjust posture. Speed, accuracy, and viewing distance increased as the font size increased. The average visual acuity reserve (VAR) at 3.56 mm font height was 6.1, and subjects adopted a larger VAR when the font size was larger. There was a significant productivity gain of 3 correct clicks/min and 8% reduction in perceived task difficulty for each 1 mm of font size increase ($p < 0.0001$), which was more pronounced in the young group. The presence of glare also led to a reduced viewing distance. The implication is that small (0.2 log unit, two lines on a visual acuity chart) increases in font size can increase productivity up to 30% and reduce mental pressure from perceived task difficulty for visually demanding tasks. This effect was present for both the young and older/presbyopic individuals.

Chapter 4 presents the second part of the full-factorial, repeated measure study. The results demonstrate the benefits (lower visual and neck discomfort and more neutral postures) of using a larger font size while performing visually demanding tasks. The presbyopic group (wearing bifocal or multifocal glasses) had a 15.9° larger head extension angle than the younger group ($p < 0.0001$); they also reported higher neck and shoulder discomfort. There was no significant difference between these two groups for other postural angles or distance measures. Only font size had an effect on visual discomfort ($p < .0001$); reducing font size from 3.56 mm to 1.78 mm caused a 48% (8.9/100) increase in visual symptom rating. Every 1 mm decrease in font height led to forward movement of 40.7 mm for the torso ($p < 0.0001$) and 3.5 mm for the head ($p < 0.0001$). A 3.5 mm forward head posture is equivalent to 0.64 kg more load on the neck extensor muscles (Cailliet, 1981). Regardless of the font size, torso postural change contributed more to viewing distance reduction than did chair positioning: torso flexion, chair reposition, and head forward contributed to 77.8%, 4.3%, and 2.7% of the reduction in viewing distance, respectively. Reflective glare was associated with higher neck symptoms and non-neutral head postures. When the glare was present, the head forward distance did not increase, but the head moved to the side by 8.83 mm ($p = 0.023$). Given the improvement in productivity, visual and neck symptoms, and postures, we recommend that computer users select font sizes close to 24 arcmin for visually intensive tasks and reduce the impact of glare on the computer monitor. This recommendation is slightly higher than the current ISO recommendations in ISO 9241-3:1992 and ISO 9241-303:2011 (International Organization for Standardization, 1992, 2011).

Future Studies

Vision Characteristics

Although the studies presented in these chapters identified some important findings related to certain vision characteristics, such as divergence limit and presbyopia there are other common visual conditions in the population that should be studied. For example, age related visual conditions in the population (e.g. convergence insufficiency, cataracts, macular degeneration, and color sensitivity change) can affect visual performance and should be studied. The effects of oculomotor demands, font size, and glare should be investigated with subjects who have specific, disabling vision conditions. For example, convergence insufficiency is the reduced convergence ability at near distances and presents as a set of “nonspecific” symptoms, such as headache, eyestrain, and instability of gaze during reading. Convergence insufficiency could be studied.

Convergence insufficiency, which has a prevalence of 3%-5%, is under-referred and often remains untreated (Scheiman et al., 2005). People with this condition prefer longer viewing distances to alleviate the visual demands from near work. Therefore, there is a potential tradeoff between opposing needs of vision: though it is desirable to have a larger VAR, there is a constraint to stay further away from the monitor. This condition is related to presbyopia because part of convergence is contributed by accommodative-convergence; as one loses the ability to accommodate, one also is less able to converge. The effect on symptoms may be more pronounced than presbyopia.

Preparation for and Validation in the Field

Although the studies presented in these chapters identified some important findings, the laboratory-based nature, short-task duration, limited ranges of font size and glare, only one type of monitor setting, and a simplistic visual search involving matching nonsense word tasks all limit the ability to extrapolate the conclusions to a real-world situations. Some examples for future research are to validate the findings for longer task durations. Most employees work more than three hours on a computer per day, and it is not uncommon to be on a computer for 30 or more hours per week (IJmker et al., 2007). It is unclear how the viewing distance would vary with even smaller fonts that are capable of being displayed on higher resolution monitors and smaller handheld devices. More research is needed to determine how the VAF response scales to lowercase letters; the current international standards and recommendations use capital letters but in reality 94.5 % of English texts are lowercase (Jones & Mewhort, 2004). We used a monitor with a matte surface so that the effect of glare would be smaller compared to when one uses a glossy screen. Glossy screens are becoming more popular and touch sensing screens and glare off of these screens should be studied. Whether the glare effect has a dose-response curve or whether there is a threshold that would lead to a significant change in symptoms and postures are two questions that remain unanswered. Also, the reflective glare in an office environment can vary, possibly covering larger and multiple screen areas or producing reflective images that can lead to an unstable accommodation. This would make the glare-mitigating behavior harder to predict. In brief, our laboratory findings should be confirmed with experimental field studies. In addition more laboratory conditions should be explored.

The Design of a Field Study

Even though the research in this dissertation established quantitative relationships between the variables investigated, these effects have not been validated in the field, where there is more variability in the population characteristics, the work being done, and the environment. To improve the power of the study, a crossover design should be considered to reduce confounding of the personal and environmental variables present in the workplace. In addition, since font size has had large and significant effects on many outcome measures it is a good candidate for a low-cost intervention study in a workplace where computer use is intensive and vision and neck pains are common. Using the findings reported in this dissertation, one could determine the optimal font size for higher productivity and prevention of symptoms by achieving recommended VAF (~23 arcmin) and VAR of 3-6 with some knowledge of one's preferred viewing distance and focal range. Such a study could also evaluate the effect on productivity of reduced information content on the screen with increased font size. The findings may support the development and evaluation of future intervention programs in the workplace as well as serve as a guideline for user interface design.

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