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

Peiyi Ko, **Anand Mohapatra**, **Ian Bailey**, University of California, Berkeley, California, **James Sheedy**, Pacific University, Forest Grove, Oregon and **David Rempel**, University of California, Berkeley, California

Nineteen young (18-35 year-old) and seven older presbyopic (55-65 year-old, wearing bifocal or progressive glasses) subjects with the same average visual acuity at near distance participated in this full-factorial, repeated measures study with two trial factors: font size (capital letter heights of 1.78, 2.23, and 3.56 mm) and reflective glare. The monitor location was fixed, but subjects were allowed to move their bodies and the chair while performing visually demanding tasks. The productivity improved up to 30% when using a large font size (average visual angle 23.4 arcmin) compared to a smaller font size (14.2 or 16.4 arcmin, $p < .0001$). The relative contributions of torso flexion (78%), head forward (3%), and chair reposition (4%) to changes in the viewing distance remained constant across font size conditions. Reflective glare had no effect on productivity measures but led to reduction of viewing distance ($p < .0001$). There were no significant differences between the two age groups.

INTRODUCTION

Multiple psychophysical studies have shown that a larger font size is associated with faster reading speeds (Legge & Bigelow, 2011; Whittaker & Lovie-Kitchin, 1993). It was suggested that, for printed materials, character size has a logarithmic relationship with reading speed at set viewing distances. Visual acuity reserve (VAR) is the ratio of a given print size to the visual acuity (VA) threshold for identifying letters. It has been suggested that, for printed materials, VAR has a logarithmic relationship with reading speed at a set viewing distance, and that this relationship holds up to a critical print size at nearly four times the size at the visual acuity threshold of the viewer (Yager, Aquilante, & Plass, 1998). It is unclear whether this relationship holds for natural viewing conditions using visually demanding text-based tasks where users' postures and reading methods are not constrained. Visual Angle of Font (VAF) is approximately the ratio of the font height to viewing distance. There have been several recommendations for the range of VAF to be adopted for character size, mostly between 16-22 arcmin range (International Organization for Standardization, 1992, 2011).

Presbyopia is the age-related an inability to adjust focus (i.e., accommodate; Fisher, 1973; Glasser & Campbell, 1998; Schachar, 2006). Typically, presbyopia is manifested 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 and becomes absolute upon 55 years of age. In a study using Chinese characters and an electronic paper display, age had an effect on preferred viewing distance; and the proofreading rate of the older group (50-70 years of age, 1.25 word/sec) was slightly but significantly slower than that of the young (21-35 years of age, 1.76 word/sec) and middle age (36-49 years of age, 1.74 word/sec) groups (Wu, 2011). Progression state of presbyopia and different prescriptions of reading glasses may have affected the findings for viewing distance and productivity. Reflective glare on a computer screen reduces contrast and may compromise productivity. The effect may be different for young and older users as intraocular light scatter increases with age (Ben-Sira, Weinberger, Bodenheimer, & Yassur, 1980). Bailey and Bullimore (1991) reported that older subjects (mean age of 64.9 years) were more susceptible to disability glare than younger subjects (mean age of 28.4 years). In addition, glare may interfere more with productivity for the older worker than for the younger worker. Sheedy, Smith, and Hayes (2005) reported that older subjects (mean age of 55.5 years) take longer to perform a visual task requiring repetitive transitions between brighter areas of surrounding luminance and dimmer areas of a computer display than younger subjects (mean age of 27.9 years). The difference may depend on the contrast sensitivity (i.e., ability to discriminate luminance contrast) of the older subject, which is affected by ocular conditions such as the presence of cataracts. Together, 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. Daum et al. (2004) demonstrated that even minor vision problems, such as blurring due to astigmatic refractive error, could result in lower performance. In the workplace, font size, and reflective glare may also affect visual performance and thus task performance. However, these effects have not been well quantified.

High prevalence and incidence of neck/shoulder musculoskeletal symptoms have been reported for computer office workers in a wide range of occupations (Gerr et al., 2002; Klussmann, Gebhardt, Liebers, & Rieger, 2008). Postural and visual stress have been identified as important risk factors for neck and shoulder musculoskeletal symptoms (Treaster, Marras, Burr, Sheedy, & Hart, 2006). It also has been suggested that, without adjusting the default "out-of-box" font size, the VAF is smaller than recommended, which then induces neck flexion, forward head posture, and thoracic spine flexion; this ultimately leads to neck and shoulder symptoms (Rempel, Willms, Anshel, Jaschinski, & Sheedy, 2007). However, viewing distance can typically be changed through a combination of postural adjustments and chair position changes. Though the former, if sustained for prolonged period of time, can lead to musculoskeletal discomfort or even a disorder, the latter will not. Therefore, it is important to determine, whether posture adjustment is a

 DOI 10.1177/1071181312561514

more common mode for changing viewing distances compared to seating position adjustment.

PURPOSE

This laboratory study examined the effects of common factors including presbyopic vision (user characteristics), font size (display setting), and reflective glare (visual environment) on productivity and postures of computer users while performing visually demanding text-based tasks. In addition to characterizing these effects and interactions among the factors, users' approach to postural change for reducing viewing distance under natural viewing conditions was evaluated (i.e., allowed the movement of the body and the chair). The findings may be useful for setting the default font size for computer programs and for training individual office workers on the font size they should select for their applications. In addition, the implications for ISO standard recommendations on visual angle is discussed (International Organization for Standardization, 1992, 2011).

METHOD

Nineteen young (18-35 years of age) and seven older presbyopic (55-65 years of age) subjects with 20/16 visual acuity at near and normal contrast sensitivity participated in this full-factorial, repeated measures study with two trial factors: font size and reflective glare. The presbyopic subjects were required to wear their usual bifocal, multifocal, or progressive addition lens (PALs) during the experiment; they had an average of +1.5 D reading magnification.

The three font sizes of Arial type had capital letter heights of 1.78, 2.23, and 3.56 mm (8, 10, 16 pt in MS Word with 100% zoom on a 20.1" display with 1600x1200 resolution). The monitor location was fixed after adjusting for the anthropometry to have the same initial glare exposure (Figure1). Yet during the experiments the 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, and word processing. An active motion analysis system (OptoTrak 3020, Northern Digital, Ontario, Canada) was used for posture measurements (Figure 2); head, torso, seat, and display orientations were recorded at 30 Hz.

This experiment allowed for a free adjustment of the body and the chair and examined the effect of font size on viewing distance, VAF, and VAR, given the same VA of users in a different age group. We also calculated the amount of the contribution that postural change (torso and head) and chair reposition to the reduced viewing distance. This was done by computing the changes in these measures during the three font size conditions compared to those 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 horizontal viewing distance changes (dVDx) through torso (dTD), chair (dCD), and head forward (dHF) adjustments under three font size conditions were reported.

Intermediate variables were the VAF and VAR. VAR is the ratio of VAF to the subject's visual acuity. The VAF was estimated using the following formula (font height and viewing distance in the same unit):

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

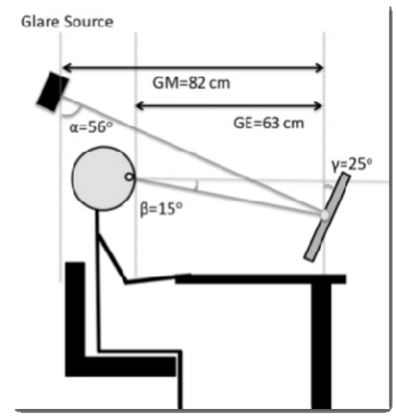

Figure 1. Diagram of the Workstation Setup and Initial Eye-Monitor-Glare Geometry: The glare source is a LED array. The glare-to-monitor (GM) and glare-to-eye (GE) distances were set while the subject was comfortably reclined in the chair. The glare geometry setup fell within the standard setup suggested by the Illuminating Engineering Society of North America (IESNA) Office Lighting Committee (1993).

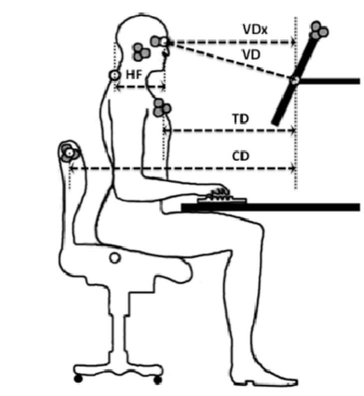

Figure 2: Markers (gray: real markers, white: virtual markers) and Distance Measures, Including: Diagonal Viewing Distance (VD), Horizontal Viewing Distance (VDx), Horizontal Torso-to-Monitor Distance (TD), Horizontal Canthus-to-C7 or Head Forward and Distance (HF), Horizontal Chair-to-Monitor Distance (CD)

The VAR used here is calculated based on the ratio of VAF to the subject's visual acuity at 40cm. If a subject had a visual acuity of 20/X, then:

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

Differences among the factor levels for all outcome measures were initially evaluated by repeated measures ANOVA 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. The presbyopic factor had no significant effect on 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 was 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 to 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

Font Size and Glare Effects on Task Performance

There was no significant effect of presbyopia on productivity (i.e., speed = number of correct clicks per minute) (p = 0.40), accuracy (p = 0.59), or perceived task difficulty (p = 0.93), so this grouping factor was removed from the remaining analyses. Both speed and accuracy were improved in the large font condition compared to the two smaller font sizes (Table 1, Figure 3). Tasks were perceived as easier in larger font sizes than in the smaller font sizes (Table 1). Neither the glare by itself nor the font size by the glare interaction term had a significant effect on the performance measures or on perceived task difficulty.

TABLE 1: Subjective Rating and Performance Measures for Three Font Sizes

	Small (1.78 mm)	Medium (2.23 mm)	Large (3.56 mm)	*p*-value[1]
Productivity (correct clicks/min)	14.2 (2.6)^{a}	14.5 (3.2)^{b}	18.5 (3.6)^{ab}	< .0001
Accuracy (%)	94.6 (4.9)^{a}	93.2 (9.3)^{b}	97.4 (2.5)^{ab}	0.0008
Subjective Rating of Task Difficulty	33.3 (16.1)^{ab}	28.8 (17.3)^{ac}	19.2 (12.4)^{bc}	< .0001

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

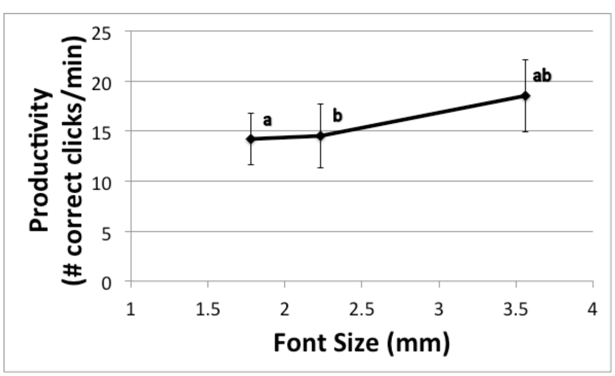

Figure 3. Productivity at the three font sizes
Significant differences between font sizes are indicated with a common superscript. Error bars are the SDs.

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

Subjects significantly reduced their viewing distance (VD) when the font was smaller or the glare was present (Table 2). The reduced viewing distance modified the effect of the font size and the glare on the intermediate variables, VAF and VAR (Table 2). There was no significant effect of the font size by the 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 pairs, indicating that the smallest font size difference that will affect these outcome measures is 0.1 log unit, which correspond to a one-line difference on a visual acuity chart.

TABLE 2: Font size (a) and Glare (b) Effects on VD, VAF, and VAR

(a)

	Small (1.78 mm)	Medium (2.23 mm)	Large (3.56 mm)	*p*-value
Viewing Distance (mm)	448.38 (88.91)^{ab}	483.58 (88.59)^{ac}	538.85 (92.23)^{bc}	< .0001
Visual Angle of Font (arcmin)	14.2 (2.9)^{ab}	16.4 (3.0)^{ac}	23.4 (4.2)^{bc}	< .0001
Visual Acuity Reserve	3.7 (0.8)^{ab}	4.3 (0.8)^{ac}	6.1 (1.2)^{bc}	< .0001

(b)

	No Glare	Glare	*p*-value
Viewing Distance (mm)	505.10 (99.13)	475.44 (92.80)	< .0001
Visual Angle of Font (arcmin)	17.4 (4.9)	18.6 (5.4)	0.0001
Visual Acuity Reserve	4.5 (1.3)	4.8 (1.5)	< .0001

Comparing the actual to the hypothetical VAFs (e.g. based on the subjects' reduced viewing distance at the smaller font conditions v. no modified viewing distance), 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 between speed and font size, where productivity was significantly higher in the largest font condition. The comparisons between the glare groups indicated that subjects may have increased VAF by moving forward in order to maintain their productivity (Figure 5).

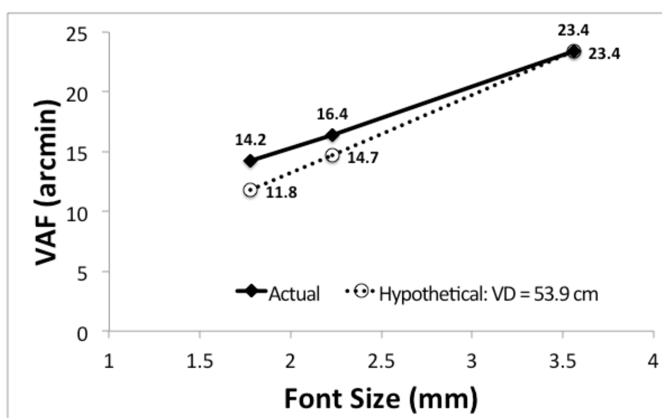

Figure 4. Comparison of the actual VAFs to the hypothetical VAFs
The hypothetical VAFs assumed that the subjects did not reduce the viewing distance at the smaller font conditions.

Based on the General Linear Regression model, font size, VAF and VAR were better predictors of productivity than the two other outcome measures. More of the variance in productivity was explained with font size ($R^2 = 0.27$) and VAR ($R^2 = 0.30$) than with VAF ($R^2 = 0.14$). 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 ($p < .0001$) and each arcmin of VAF increased productivity by 0.43 correct clicks/min ($p < .0001$). Similarly, each mm increase in font height reduced perceived task difficulty by ~7.75% ($p < .0001$).

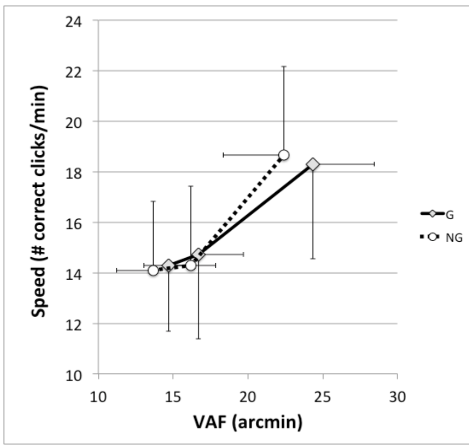

Figure 5. Relationship between speed and VAF with data stratified by the glare condition. Error bars are the SDs.

Font Size and Glare Effect on Posture

There was no significant difference between presbyopic and non-presbyopic subjects for the postural distance measures (Table 3). The overall VD was 490.27 (96.86) mm, TD was 554.85 (80.60) mm, and HF was 197.18 (33.20) mm. The posture distance results indicated that, as the font size became smaller, subjects reduced the viewing distance by leaning forward; VD and TD reduced, but HF did not increase with glare (Table 4).

TABLE 3: Distance Measures for Both Groups

	Non-Presbyopic	Presbyopic	*p*-value
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

TABLE 4: Distance Measures for (a) Font size and (b) Glare conditions

(a)

	Small (1.78 mm)	Medium (2.23 mm)	Large (3.56 mm)	*p*-value
VD (mm)	448.38 (88.91)[ab]	483.58 (88.60)[ac]	538.89 (92.25)[bc]	<.0001
TD (mm)	520.25 (71.80)	548.98 (75.50)	595.33 (77.17)	<.0001
HF (mm)	200.09 (32.67)[a]	197.76 (35.88)	193.69 (31.19)[a]	0.05

(b)

	No-Glare	Glare	*p*-value
VD (mm)	505.10 (99.13)	475.44 (92.80)	.0002
TD (mm)	568.67 (81.65)	541.03 (77.60)	.0001
HF (mm)	196.51 (32.00)	197.85 (34.54)	0.54

In the experimental conditions where the overall task difficulty was higher and where glare was present, small font size induced the largest change in horizontal viewing distance (204.22 mm) while the changes were smaller for the medium and large font size conditions (168.37 mm and 110.68 mm respectively). However, there was a small fraction of dVDx that remained unexplained (Table 5).

TABLE 5: Distance Measures for (a) Font size and (b) Glare conditions

	Small (1.78 mm)	Medium (2.23 mm)	Large (3.56 mm)
dTD (mm)	160.2 (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

Even though the reduction of the viewing distance decreased with an increase in font size, 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 6).

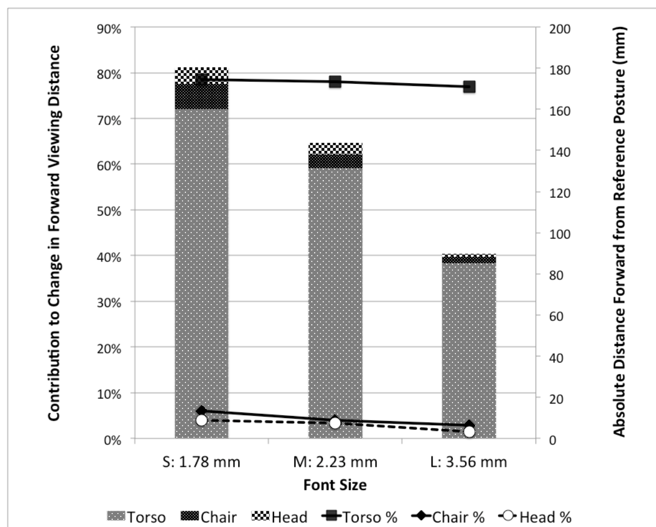

Figure 6. Absolute Changes and Proportions of Changes in Viewing Distance Changes through Torso (dTD), Chair (dCD), and Head Forward (dHF) Adjustments Given Three Font Sizes

General linear models were used to explore the relationships between the three factors 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 ($p < .0001$), 4.54 mm ($p = .045$), and 3.48 mm ($p < .0001$) forward change for *dTD*, *dCD*, and *dHF*, respectively. When the reflective glare was present, torso moved forward 27.65 mm ($p < .0001$). Presbyopia did not affect the response of one's posture in performing visually demanding tasks.

DISCUSSION AND CONCLUSIONS

Overall, the study findings suggest that the selection of monitor placement and font size are important factors for productivity when using a computer. Specifically, productivity improved up to 30% and 3% in accuracy when users employed the larger font (3.56 mm; VAF of 23.4; VAR of 3.7) compared to the smallest font (14.2 mm; VAF of 14.2; VAR of 6.1). The font size differences were 60%, 0.2 log unit, or two lines on the visual acuity chart, from 2.23 mm to 3.56 mm. 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. Our study found that small increases in font size can increase the speed and accuracy of visually demanding computer based tasks. This is at the high end of the productivity increase (2.5% - 28.7%) that was observed by Daum et al. (2004) due to astigmatic refractive correction. Based on their cost-benefit analysis on the visual correction for an employee ($268 cost) with a salary of $25,000 dollars per year, a conservative estimate of 2.5% increase in productivity provides a favorable cost-benefit ratio of 2.3:1. Given the average + 1.5 D prescription of our presbyopic subjects, the optimal viewing distance range is 40-66cm. This may be why the viewing distances of the two groups did not differ significantly in the group comparison. However, there was a significant productivity gain of 3 correct clicks/min and 8% reduction in perceived task difficulty with each 1 mm of font size increase ($p < .0001$), which was more pronounced in the young group.

Our observation that subjects moved toward the screen when the reflective glare was present on the screen, has not, as far as we know, been reported by other researchers. It is most likely that subjects moved forward – thereby reducing the viewing distance and increasing VAF and VAR – to mitigate the reduction of character-background contrast from the glare. It is also possible that subjects moved forward to change the glare -monitor - eye geometry and to reduce the offending 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 (Bailey & Bullimore, 1991; Sheedy 2005). Our study provides information regarding the actual luminance within a common volume of working space. An additional glare effect on posture that was analyzed but not reported in the result is that subjects on average moved the head to the side for 9.28 mm ($p < .0001$, data not shown), indicating this amount of reflective glare can also lead to subtle changes in posture intended to modify the eye-monitor-glare geometry. Some effects may become more prominent with a longer exposure time.

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 (Figure 6). 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. There were about 2 cm reduction in the viewing distance in the direction toward the monitor that was not explained by the three components. Also, the experiment setup could have been unable to capture the shifting in one's seating depth due to the limited field of view of the motion capture cameras (Table 5).

Given the improvement in productivity and in posture that we found, we recommend computer users to select font sizes close to 24 arcmin for visually intensive tasks and to reduce the impact of glare on the computer monitor. This is at the high end of (and slightly over) the ISO recommendations (International Organization for Standardization, 1992, 2011).

ACKNOWLEDGEMENT

This study was supported in part by a Graduate Training Grant from the National Institute for Occupational Institute and Health (NIOSH 42 OH008429).

REFERENCES

Bailey, I. L., & Bullimore, M. A. (1991). A new test for the evaluation of disability glare. *Optometry and Vision Science: Official Publication of the American Academy of Optometry*, 68(12), 911–917.

Ben-Sira, I., Weinberger, D., Bodenheimer, J., & Yassur, Y. (1980). Clinical method for measurement of light backscattering from the in vivo human lens. *Investigative Ophthalmology & Visual Science*, 19(4), 435–437.

Daum, K. M., Clore, K. A., Simms, S. S., Vesely, J. W., Wilczek, D. D., Spittle, B. M., & Good, G. W. (2004). Productivity associated with visual status of computer users. *Optometry (St. Louis, Mo.)*, 75(1), 33–47.

Gerr, F., Marcus, M., Ensor, C., Kleinbaum, D., Cohen, S., Edwards, A., Gentry, E., et al. (2002). A prospective study of computer users: I. Study design and incidence of musculoskeletal symptoms and disorders. *American Journal of Industrial Medicine*, 41(4), 221–235.

IESNA Office Lighting Committee. (1993). *American National Standard Practice for Office Lighting* (p. 63). USA: Illuminating Engineering Society of North America, RP-1.

International Organization for Standardization. (1992). *Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs). Part 3: Visual Display Requirements*.

International Organization for Standardization. (2011). *Ergonomics of Human-System Interaction -- Part 303: Requirements for Electronic Visual Displays*.

Legge, G. E., & Bigelow, C. A. (2011). Does print size matter for reading? A review of findings from vision science and typography. *Journal of Vision*, 11(5):8, 1-22.

Rempel, D., Willms, K., Anshel, J., Jaschinski, W., & Sheedy, J. E. (2007). The effects of visual display distance on eye accommodation, head posture, and vision and neck symptoms. *Human Factors*, 49(5), 830-838.

Sheedy, J.E., Smith, R., & Hayes, J. (2005). Visual effects of the luminance surrounding a computer display. *Ergonomics*, 48(9), 1114-1128.

Treaster, D., Marras, W. S., Burr, D., Sheedy, J. E., & Hart, D. (2006). Myofascial trigger point development from visual and postural stressors during computer work. *Journal of Electromyography and Kinesiology*, 16(2), 115–124.

Whittaker, S. G., & Lovie-Kitchin, J. (1993). Visual requirements for reading. *Optometry and Vision Science: Official Publication of the American Academy of Optometry*, 70(1), 54-65.

Wu, H-C. (2011). Electronic paper display preferred viewing distance and character size for different age groups. *Ergonomics*, 54(9), 806-814.

Yager, D., Aquilante, K., & Plass, R. (1998). High and low luminance letters, acuity reserve, and font effects on reading speed. *Vision Research*, 38(17), 2527-2531.