Discomfort glare and psychological stress during computer work ─ Subjective responses and associations between neck pain and trapezius muscle blood flow

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ABSTRACT

Purpose

Exposure to additional environmental stress during computer work, such as visual and psychological demands, is associated with increased eye and neck discomfort, altered moods, and reduced well-being. The aim of this study is to elucidate further how subjective responses in healthy, young females with normal binocular vision are affected by glare and psychological stress during computer work, and to investigate possible associations between trapezius muscle blood flow and neck pain development.

Methods

Forty-three females participated in a laboratory experiment with a within-subject design. Four ten-minute computer work conditions with exposure to different stressors were performed at an ergonomically optimal workstation, under the following series of conditions: no additional stress, visual stress (induced as direct glare from a large glare source), psychological stress, and combined visual and psychological stress. Before and immediately after each computer work condition, questionnaires regarding different visual and eye symptoms, neck and shoulder symptoms, positive and negative state moods, perceived task difficulty, and perceived ambient lighting were completed. Associations between neck pain and trapezius muscle blood flow were also investigated.

Results

Exposure to direct glare induced greater development of visual/eye symptoms and discomfort, while psychological stress exposure made participants feel more negative and stressed. The perception of work lighting during glare exposure was closely related to perceived stress, and associations between visual discomfort and eyestrain, and neck pain were observed in all conditions. Furthermore, participants with high trapezius muscle blood flow overall reported more neck pain, independent of exposure.

Conclusions

Exposure to visual and psychological stresses during computer work affects the development of symptoms and negative moods in healthy, young females with normal binocular vision, but in different ways. The results also demonstrate the complex interactions involved in symptom development and lighting appraisal during computer work. When optimizing computer workstations, the complexity of the field must be taken into account, and several factors, including visual conditions, must be considered carefully.

Keywords: glare; stress; computer work; vision; eyestrain; neck pain; mood

INTRODUCTION

Computer workers generally report a high prevalence of musculoskeletal pain. The symptoms most frequently reported are pain or discomfort in the neck and shoulder area (Kaliniene et al. 2016; Larsson et al. 2007; Mohanty et al. 2017; Woods 2005). Already in the 1700's, Ramazzini realized that musculoskeletal pain were associated with ergonomic factors (Piccoli 2003), and later Duke-Elder found an association between occupational near work and visual symptoms (Duke-Elder 1930). Near work, such as computer work, is visually demanding as several eye muscles are involved in keeping a near object clearly focused and single (Lie et al. 2000; Lie and Watten 1994). The ciliary muscle around the lens contracts to focus the object (accommodation), the extraocular muscles move the eyes medially (convergence), and the iris sphincter muscle reduces the pupil size (miosis) (Atchison and Smith 2000). Furthermore, blink rate is reported to decrease, inducing dry eyes (Rosenfield 2011; Skotte et al. 2007; Wolkoff 2008). Consequently, visual discomfort, tired and uncomfortable eyes, blurred vision and headache develop during computer work (Aarås et al. 2005; Rosenfield 2011; Wolkoff et al. 2005; Woods 2005).

Intensive near work like computer work often induces static posture for a prolonged period. The body structures involved in the musculoskeletal strain of any posture constitute a complex system of interrelated muscles, joints, and ligaments. Research has shown increased activation of the muscles in the neck and shoulder area, such as the trapezius muscle, during visually demanding work. Besides contributing to a steady position of the head and upper cervical spine, this activation likely supports efforts to stabilize gaze and maintain a clear image on the retina (Biguer et al. 1982; Lie and Watten 1987; Richter 2014; Richter and Forsman 2011). Visual discomfort and reduced vision are related to neck pain in computer workers (Hayes et al. 2007; Helland et al. 2008; Richter et al. 2012; Richter et al. 2011; Sánchez-González et al. 2018; Wiholm et al. 2007; Zetterberg et al. 2017). Thus, the literature shows that computer workers appear to be at risk of developing musculoskeletal and/or visual problems, which in turn may reduce well-being and work efficiency and lead to illness and sick leave.

Poor visual conditions during computer work, like glare exposure, may also contribute to pain development (Blehm et al. 2005; Gowrisankaran et al. 2007; Mork et al. 2016; Nahar et al. 2007). The two most common forms of glare are disability glare and discomfort glare. Disability glare occurs when a reduction in visual performance caused by light scattered in the ocular media is present and results in reduced contrast and visibility in the field of view (Vos 2003). Discomfort glare refers to the sensation of visual annoyance and distraction because of high luminance or high luminance contrasts within the visual field (Mainster and Turner 2012; Vos 2003).

In addition, glare exposure has been reported to result in increased orbicularis oculi muscle activity and decreased aperture size (eyelid squinting), decreased pupil size, increased trapezius blood flow, altered eye movements, decreased reading performance, and reduced productivity (Berman et al. 1994; Glimne et al. 2015; Glimne et al. 2013; Gowrisankaran et al. 2007; Hemphälä and Eklund 2012; Lin et al. 2015; Mork et al. 2016; Mork et al. 2018).

Several factors have been proposed to contribute to computer-related neck pain development, including posture, duration of computer work, psychological stress, repetitive movements, prolonged static loads, and psychosocial effects of the work environment (da Costa and Vieira 2010; Gerr et al. 2004; Hagberg 1984; Jun et al. 2017; Larsson et al. 2007; Linton 2000; van der Windt et al. 2000; Wahlström 2005). The association between psychosocial factors and musculoskeletal pain has been linked to stress and attention-related muscle activity. Electromyography (EMG) studies have shown that situations that demand continued attention elicit low-level muscle activity in the trapezius muscle and in other muscles. The muscle activity appears to have no relation to any biomechanical demands arising from the work task itself (Wærsted 2000; Wærsted et al. 1996). This muscle activity may be linked to increased autonomic and cortical arousal found in the physiological stress response. Findings showing that the same motor units appear to be activated by both mental and physical loads (Lundberg et al. 2002), lend additional support to this notion.

Individual differences may represent an additional challenge to the understanding of pain and discomfort associated with computer work. It is known that different personalities have different autonomic reactions to acute psychological stressors (Chida and Hamer 2008; Jonassaint et al. 2009). Dispositional tendencies to experience negative emotions, often called negative affect, may be of special interest in this regard. Trait negative affect is known to influence somatic complaints, perceived stress, depressive symptoms, and fatigue (Denollet and De Vries 2006; Spink et al. 2018). In addition, trait negative affect is associated with increased autonomic arousal and thus the physiological stress response itself (Kehoe et al. 2013; Kreibig 2010). However, research also indicates that transient emotions, often called state emotions or moods, are important in the understanding of stress in the workplace. Stress increases the activation of the hypothalamic–pituitary–adrenal (HPA) axis, with increased secretion of cortisol as a result. Increased cortisol levels appear to influence mood by regulating feelings of arousal and affect during and after stressful events (Het and Wolf 2007; Kuhlmann et al. 2005). Furthermore, studies indicate that mood is influenced by environmental factors. Research by Veitch et al. (2013), reports that mood mediates the effect of lighting appraisals on important work-related variables such as job engagement and well-being. This result accords with Wahlström's (2005) explanation of the development of pain and discomfort during computer work as a complex interaction between the individual's physical and psychological demands and the work organization.

Acknowledging the complexity of research associated with work-related pain development, the aim of the current study is to explore how visual and psychological stress during computer work affects self-reported symptoms and positive and negative state moods in healthy, young females with normal binocular vision. An additional aim is to investigate the connection between trapezius muscle blood flow and development of neck pain. The present study is part of a larger study that also involves physiological measures (Mork et al. (2018).

METHODS

Subjects

The paper is part of a larger study, and details on subjects and laboratory set-up are published in Mork et al. (2018). Forty-three healthy experienced female computer users (21.4 ± 2.4 years, mean ± SD, range 17–27) with normal vision carried out four separate computer work sessions, each lasting ten minutes. All participants were students recruited from the University of South-Eastern Norway, Kongsberg. The Regional Committee for Medical and Health Research Ethics, Norway (2013/610), approved the study before start of data collection. In addition, the study followed the tenets of the 1964 Helsinki declaration and its later amendments. Before study participation, all subjects received verbal and written information about the study, and all provided written informed consent.

Prior to participating an optometric examination was performed at the National Centre for Optics, Vision and Eye Care, Kongsberg, Norway to ensure that participants had normal or corrected to normal binocular vision and good eye health. Twenty did not use any correction, sixteen wore single vision glasses and seven used contact lenses during the experiment. A summary of the visual characteristics of the participants is provided Mork et al. (2018). The experiment was conducted during the winter periods (December–February) in 2015 (n=23) and in 2016 (n=20).

Exclusion criteria were chronic pain in the neck and shoulder area in the previous six months, history of eye trauma or surgery, dyslexia, mental illness, and systemic disease or regular use of medications affecting circulation, pain sensation, vision, or visual comfort.

Laboratory set-up and design

During the entire experiment participants were seated with a viewing distance of 65 ± 6 cm (mean ± SD) facing a 24′′ anti-reflection HP LA2405x LCD- computer screen (1920 x 1200 pixels, mean refresh rate 69.5 Hz). The sitting position and the lighting conditions were individually optimized according to international and national regulations (Arbeidsplassforskriften 2011; Directive 90/270/EEC 1990; Lillelien et al. 2012). The font size was 12 points Times Roman (Captial E: 3 mm), and the initial gaze angle was 21± 2° (mean ± SD, n = 42) downwards. Postural angles were measured continuously with inclinometers, and changes in viewing distance were reflected in back angle changes. The ambient air temperature and relative humidity was 22 ± 1 °C and 38 ± 9 % (mean ± SD, n = 42). For details, see (Mork et al. 2018).

The laboratory experiment had a counterbalanced, fully factorial, repeated 2x2x4 design. The computer task in all four conditions was to read a text on a computer screen, identify spelling errors in the text, and mark these errors in bold using a standard wireless laser mouse as a pointing device. All four computer work conditions consisted of the same parts: (1) a one-minute rest session before computer work (*rest*), (2) ten minutes of computer work, (3) a break (13.9 ± 2.1 min, mean ± SD, n = 43), and (4) a one-minute rest session after the break to measure recovery (*recovery*). The recovery session after one condition was concurrent with the rest session before the next condition. In each condition, the participants performed the same computer task, but were exposed to different stress requirements, as listed below:

1. Low stress (LS): No additional stress exposure except for the computer task itself; the workstation lighting was appropriate.

2. Visual stress (VS): Exposure to direct glare from two large luminaires placed behind the computer screen simulating a window in an office. The luminance of the glare source was 4634 ± 749 cd/m^2 (mean ± SD) measured across the luminaire screens. The glare source simulated a window placed behind the computer screen, and the luminance levels was close to that from a window on an overcast day.

3. Psychological stress (PS): The participants were exposed to psychological stressors ; lighting conditions were appropriate. Three combined psychological stress-inducing procedures were used: (1) participants were told to work as rapidly and accurately as possible and that their performance would have a major influence on the test outcome; (2) participants were told that they would have to answer questions from the text they read; and (3) a video camera was turned on to monitor the participants throughout the computer work session. The participants were aware that the camera was recording. The first stressor put time and precision pressure on the participants, whereas the two latter were social-evaluative threats.

4. Visual and psychological stress (VPS): The exposures described in VS and PS occurred simultaneously.

The luminance levels during LS and PS (with the glare source turned off) were within the luminance ratio of 5:3:1 recommended for a computer work context (Anshel 2007; Piccoli 2003). The luminance was 155 cd/m^2 in the working field (computer screen turned on), 90 cd/m^2 in the immediately surrounding area (desktop area closest to computer screen) and 61 cd/m^2 in the background area (the wall behind the glare source and peripheral parts of the desktop). During VS and VPS with the glare source turned on, the luminance ratio was 1:3:30 (155 cd/m^2: 520 cd/m^2: 4634 cd/m^2). A Hagner Universal Photometer (Modell S4, Sweden) was used for the luminance measurements, and values are the average luminance measured from the participant's eye during testing towards several different measure points across the glare source surface. (For further details, see Mork et al., 2018).

Measurements

The participants completed a questionnaire immediately after the rest recording, before the start of the 10-minute computer work period, and another questionnaire immediately after the computer work period for each of the four conditions. These questionnaires consisted of questions with 100 mm Visual Analogue Scales (VAS) (Kildeso et al. 1999); the participants were asked to rate the degree to which they experienced different subjective symptoms, the extent to which they felt different positive and negative state moods, and how they perceived the workstation lighting and task difficulty. The left end-points (0 mm) on the scales represented 'nothing', whereas the right end-point (100 mm) represented 'very much'. Table 1 provides an overview of the questionnaire and a grouping of the state moods. Because of an observed necessity for supplementary information about symptoms and moods, some questions were added during the 2016 test period.

Subjective symptoms

Eye-related tiredness, eye pain, neck pain, and shoulder pain were recorded during both test periods. The remaining symptoms – photophobia, dry eyes, head tiredness, headache and blurred vision – were registered only during the second test period (Table 1).

Table 1 approximately here.

Subjective symptoms were measured both before and after each computer work condition, and the participants were asked to rate the degree to which they experienced the different symptoms at the precise moment they completed the questionnaire.

To investigate the total development of eye symptoms for each participant, an index for eye symptom score (average score (mm VAS) for all registered eye symptoms) was created. For participants in the first and second test periods, this index involved an average of two and seven eye symptoms, respectively.

Negative and positive state moods

The state moods registered in the study were strained, stressed, relaxed, uncomfortable, bored, satisfied, and concentrated (Table 1). When registering before the computer work sessions, the participants were asked to rate the degree to which they were affected by the different moods at the precise moment that they completed the questionnaire. As to measurements after the computer work sessions, participants were asked to rate the degree to which they were affected by the moods throughout the computer work sessions ('how did you feel while working?'). The registered state moods were categorized into two main groups: negative and positive (Table 1), and the indexes were made up by the average score (mm VAS) of the included moods.

Perceived workstation lighting and task difficulty

The perceived difficulty of the computer task was reported after each computer-work condition. Perceived ambient lighting at the computer workstation during computer work, however, was measured only after the conditions in the first test period, and both before and after in the second test period (Table 1).

Trait affect

To register the participants' positive and negative trait affect, the 10-item Positive and Negative Affect Schedule (PANAS) was used (Watson et al. 1988). Table 2 shows the mean scores for trait affect among the participants. The index scores for each negative (indignant, shameful, nervous, unfriendly, scared) and positive (active, watchful, inspired, determined, attentive) trait affect were used in the study as covariates to control for the influence of personality on the other measurements.

Table 2 approximately here.

Neck pain and trapezius muscle blood flow

The data in this article are part of a larger study, which also included measurement of physiological parameters such as trapezius muscle blood flow and presented in Mork et al. (2018). To investigate the associations between muscle blood flow in the trapezius and neck pain, the participants were divided into two subgroups regarding average trapezius muscle blood flow (TBF) during the four computer work conditions. The subgroups were: (1) *High TBF*: participants with TBF equal to or higher than the median value (n = 17) and (2) *Low TBF*: participants with TBF measurements lower than the median value (n = 15).

Statistics

Statistical analyses were performed using IBM SPSS Statistics (Version 24, USA). The overall statistical analyses were performed with analysis of variance (ANOVA) repeated measures, and planned contrasts were used to compare conditions and time points if the overall analysis indicated either main effects or interaction effects. Inspection of the variables revealed that several variables departed from the normal distribution; base-10 logarithm transformation was executed on these variables. For variables with normal distribution, untransformed data were used in the analysis. For most ANOVA analyses, Mauchly's test indicated a violation of the assumption of sphericity, so the Greenhouse–Geisser correction was used. An overall ANOVA was performed to investigate potential overall time effects (test order effects) throughout the experiment, independent of condition. Independent-samples t-tests were conducted to compare subgroups of participants.

RESULTS

Trait affect

Negative and positive trait affect measures were entered as covariates in the analysis. The results did not show any significant interaction effects. Thus, trait affectivity (personality) appears not to affect the measured variables differently across conditions, and the covariates were discarded from further analyses.

Visual and psychological stress on perceived task difficulty and ambient lighting

Figure 1a shows that the participants experienced the task as significantly more difficult in the two conditions with psychological stress than conditions without psychological stress: $F\ (1.0, 42.0) = 15.17, p < .000, \eta^2 = .27)$. Glare exposure (visual stress), however, affected the perceived workstation lighting negatively, as there was a glare-by-time interaction: $F\ (1.0, 19.0) = 40.85, p < .000, \eta^2 = .68)$. Figure 1b shows the differential score for how the participants perceived the ambient lighting.

Figure 1 approximately here.

Subjective symptoms

Main effects of visual and psychological stress exposure

Table 3 shows self-reported symptoms for each computer-work condition. The analysis revealed a significant glare-by-time interaction for total eye symptoms: $F(1.00, 40.00) = 6.13$, $p = .018$, $\eta^2 = .13$. Furthermore, there were significant glare-by-time interactions for eye-related tiredness: $F(1.00, 40.00) = 9.29$, $p = .004$, $\eta^2 = .19$; for head tiredness: $F(1.00, 19.00) = 5.16$, $p = .035$, $\eta^2 = .21$; and for photophobia: $F(1, 19) = 13.24$, $p = .002$, $\eta^2 = .41$. These results indicate that glare exposure led to increased eyestrain and visual discomfort during computer work.

Table 3 approximately here.

Time effects

The results further showed a main effect of time for total eye symptoms: $F(1,40) = 33.87$, $p < .001$, $\eta^2 = .46$. Among individual symptoms, time effects were also seen for eye-related tiredness: $F(1, 40) = 12.08$, $p = .001$, $\eta^2 = .23$; eye pain: $F(1, 19) = 7.08$, $p = .015$, $\eta^2 = .27$; neck pain: $F(1, 40) = 27{,}15$, $p < .001$, $\eta^2 = .40$; blurry vision: $F(1, 19) = 10.44$, $p = .004$, $\eta^2 = .36$; head tiredness: $F(1, 19) = 6.50$, $p = .020$, $\eta^2 = .26$; and photophobia: $F(1, 19) = 23.99$, $p < .001$, $\eta^2 = .56$ (Table 3). This suggests that the symptoms increased with time, independent of condition and exposure.

Positive and negative state moods

Figure 2 shows the negative and positive state moods (index) reported in the four conditions. Scores for each state mood before the start of and immediately after conditions are reported in Table 4.

Figure 2 approximately here.

Main effect of visual and psychological stress exposure

The results showed a significant main effect of psychological stress for negative state moods: $F(1.00, 42.00) = 12.69$, $p = .001$, $\eta^2 = .23$, indicating that participants reported more negative moods due to psychological stress exposure (Figure 2a). There was no significant effect of exposure to either glare or psychological stress for positive state moods (Figure 2b).

Analysis revealed a significant glare-by-time interaction for feeling uncomfortable: $F(1.00, 40.00) = 9.29$, $p = .004$, $\eta 2 = .19$; and a significant psychological stress-by-time interaction for perceived stress: $F(1.00, 41.00) = 13.23$, $p = .001$, $\eta2 = .24$, indicating that visual and psychological stresses induced different negative moods during computer work.

Time effects

The results also showed a main effect of time for perceived stress: $F(1, 41) = 71.90$, $p < .001$, $\eta^2 = .64$; feeling strained: $F(1, 41) = 43.98$, $p < .001$, $\eta^2 = .52$; and relaxed: $F(1, 41) = 17{,}92$, $p < .001$, $\eta^2 = .30$. This reflects the fact participants were more stressed and strained and less relaxed at the end of the computer work than before the start in all conditions, independent of the induced stress requirements.

Table 4 approximately here.

Trapezius muscle blood flow and neck pain

Table 5 shows that participants with high TBF levels during computer work reported more neck pain in conditions with glare and/or psychological stress, than participants with low TBF. There was no significant difference in posture between these two subgroups, except for head angle in the LS condition, during which the high TBF group showed slightly less flexion (3.5 ± 1.7 degrees vs 5.0 ± 2.5 degrees, $p = .039$).

There were no significant correlations between TBF and neck pain or eye symptoms for the study group overall.

Table 5 approximately here.

Correlation analyses

Neck pain associations

Table 6 shows that self-reported neck pain was positively associated with several of the measured eye and visual symptoms in all computer work conditions.

Table 6 approximately here.

Associations between perceived lighting and stress during glare exposure

There were positive correlations between perceived lighting and the development of stress (differential scores: during work – before start) when exposed to glare in VS ($r = 0.737$, $p < 0.001$) and in VPS ($r = 0.494$, $p = 0.027$). Figure 3 shows this association during exposure to glare only (in VS). This indicates that perceiving the workstation lighting as unpleasant during computer work with glare exposure was related to increased feelings of stress or vice versa.

Figure 3 approximately here.

Test session order

We tested how the study design with multiple conditions on the same test day affected the participants; for many of the measured parameters, there was a significant effect of time independent of the condition order. Reported eye pain, neck pain, headache, strain, boredom, head tiredness, negative state moods (index), and experience of task difficulty increased throughout the test sequence from the first to the last condition, indicating that the participants experienced more symptoms and felt more negative in later phases of the experiment than they did at the start. Scores for the variables satisfied, relaxed, and concentrated, meanwhile, decreased from the first to the last condition, indicating that the participants felt less positive in later phases of the experiment. These overall time effects might have washed out potential effects of interest. We did not find overall time effects for eye tiredness, blurred vision, photosensitivity, feelings of being uncomfortable and stressed, or the experience of the workstation lighting.

DISCUSSION

In the present study, participants with normal binocular vision were exposed to visual stress (glare), psychological stress, and the combination of these stressors during computer work in a simulated office environment. The large glare source simulated a window situated behind the screen; as expected, the lighting was perceived as significantly more unpleasant with exposure to glare than when working with appropriate workstation lighting. The surrounding luminance on a computer workstation should be even distributed and slightly below the luminance of the task for both young and older subjects (Sheedy et al. 2005). Unfavourable lighting, including glare conditions, may lead to annoyance, visual discomfort, and reduced well-being (Blehm et al. 2005; Boyce 2014). In the present study, the glare source had a mean luminance intensity comparable to an office window on an overcast day. Glare sources with lower intensities have been reported by others to be perceived as intolerable and to produce discomfort (Lin et al. 2015; Osterhaus and Bailey 1992), and the glare exposure in the present study therefore probably provoked discomfort glare, while feeling uncomfortable appears to be a mood related to this kind of visual stress.

The participants rated the task difficulty as worse during exposure to psychological stress than during computer work without psychological stress. The computer task was the same during all four computer work periods. However, the instructions and expressed expectations were different in the conditions with and without psychological stress exposure, so one possible explanation is increased cognitive load. Research has shown that stress impairs cognitive functioning by reducing attentional capacity. This effect will be more pronounced in tasks requiring intentional attention (Sandi 2013; Stawski et al. 2006), such as identifying spelling errors in text as in the present study.

Subjective symptoms

Main effects of visual and psychological stress exposure

Exposure to glare during computer work resulted in more eyestrain and discomfort than under non-glare conditions. This is consistent with earlier research (Berman et al. 1994; Blehm et al. 2005; Gowrisankaran et al. 2007; Mork et al. 2016; Nahar et al. 2007; Sheedy et al. 2003a).

One potential mechanism for discomfort and eyestrain during glare is the involvement of the orbicularis oculi muscle (Berman et al. 1994; Thorud et al. 2012). During glare, increased activity in the orbicularis oculi (eyelid squinting) is known to be an effort to reduce the amount of light entering the eye (Sheedy et al. 2003b). A glare source similar to the one used in the present study was previously shown to result in increased muscle activity in the orbicularis oculi (Mork et al. 2016). Further, Thorud et al. (2012) observed a significant positive correlation between orbicularis oculi muscle load and eye-related tiredness, and between orbicularis oculi muscle blood flow and eye-related pain during visually demanding computer work with glare and a small font size. These results suggest the possible involvement of the orbicularis oculi muscle in the development of eyestrain during computer work found in the present study.

High visual demands and increased load on intra- and extraocular muscles, such as stress on the accommodative–convergence system, are assumed to be involved in the development of eye symptoms (Bruenech and Kjellevold Haugen 2007; Sheedy et al. 2003a; Zetterberg et al. 2017). Regarding glare conditions, glare exposure have been reported to put extra load on the visual system by affecting accommodation (Shahnavaz and Hedman 1984; Wolska and Switula 1999), the binocular coordination (Glimne et al. 2013), eye movements (Glimne et al. 2015; Lin et al. 2015), and the iris muscle's regulation of pupil size (Fry and King 1975; Hopkinson 1956). Therefore, intra and extraocular muscle strain may also be involved in the glare-induced eyestrain and discomfort observed here.

In contrast to other studies (Gowrisankaran et al. 2012; Mocci et al. 2001; Ostrovsky et al. 2012), the present study did not find that psychological stress affected the development of eye symptoms. In Gowrisankaran et al.'s study (2012), increased eyestrain was reported by adding cognitive load to visual stress (induced refractive error), compared to only visual stress. However, the discrepancy between the present study and previous research regarding psychological stress and eyestrain may be due to differences in study design and task characteristics.

In the debriefing after the experiment, all participants confirmed that one or more of the induced psychological stressors had affected them, but there were intersubjective differences in what they reported to be the most stressful factor. This suggests that inducing multiple psychological stressors in studies with a similar design might be useful.

Time effects

There were significant time effects in the present study for both eye symptoms and neck symptoms, indicating a significant increase in general symptoms during computer work compared to rest, independent of exposure. This supports the notion that working on a computer screen is associated *per se* with the development of neck symptoms and eye discomfort (Blehm et al. 2005; Duke-Elder 1930; Köpper et al. 2016; Mork et al. 2016). Prolonged computer work requires sustained activation of intra- and extra ocular eye muscles involved in the near response (e.g. accommodation, convergence, miosis). This has been found to be associated with eyestrain development (Blehm et al. 2005; Bruenech and Kjellevold Haugen 2007; Jaschinski-Kruza 1991; Mork et al. 2016).

The increase in eyestrain during computer work *per se* may also have been influenced by other risk factors present during computer work, such as attention-decreased blinking, increased amounts of incomplete blinks, and a higher gaze angle compared to reading hard copy text with depressed gaze. These factors may contribute to increased corneal exposure and inducing symptoms such as dry and irritated eyes (Rosenfield 2011; Wolkoff 2008). However, no significant increase in dry eye symptoms was found in the present study. The computer tasks were short in duration and were possibly not sufficiently lengthy to affect self-perceived dry eye levels. Furthermore, corneal exposure and incomplete blinks were not measured, and we cannot elucidate how these factors were involved in the eyestrain observed increase during all conditions. Köpper et al. (2016) showed that placing the screen and the hard copy text in a similar paper-like gaze position eliminated the differences in reported eyestrain during reading on a computer screen compared to hard copy reading. This supports previous findings that show beneficial effects on the visual system, visual symptoms, and musculoskeletal symptoms of lower gaze angles during computer work (Fostervold 2003; Fostervold et al. 2006) and points out the importance of optimal gaze angle in preventing discomfort during computer work. Further, it should be mentioned that adverse chemical, physical and biological agents in the indoor environment might also cause eye symptoms (Piccoli 2003). In our study, air temperature and humidity were measured during testing periods to ensure a stable lab environment. However, as environmental agents were not measured, we cannot totally exclude any potential influence on the time effects found in this study, but this is most likely negligible.

The increase in neck symptoms from rest to computer work was between 2–6 mm VAS (Table 3). In the literature, a difference of 10–15 mm VAS is considered the minimum clinically significant difference in pain scores (Kelly 2001; Ostelo et al. 2008). However, ten minutes is a short period of exposure compared to prolonged computer work in actual work settings, and studies with more extensive work periods often report more pronounced neck symptoms (McLean et al. 2001; Mork et al. 2016; Strøm et al. 2009a). Strøm et al. (2009a) showed a mean increase in pain in the neck and shoulder area of approximately 40 mm VAS through 90 minutes of computer work in healthy, pain-free subjects. In accordance with the current study, the increase in the first 15 minutes in their study was 2–3 mm VAS. In Strom et al.'s (2009a) study, symptom development became more pronounced throughout the working period, supporting the notion that neck and shoulder pain increases with sustained computer work. Hence, longer exposure time in the present paper likely would also have resulted in more pronounced neck pain development.

Neck pain and trapezius blood flow

Participants with high TBF during computer work experienced significantly more neck pain than participants with low TBF in all conditions except the low stress condition (Table 5). Different hypotheses concerning the pathogenesis of work-related neck pain have been proposed (Hägg 1991; Johansson and Sojka 1991; Knardahl 2002; Sjøgaard et al. 2000), but the underlying mechanisms remain unclear. Larsson et al. (2007) pointed to the importance of local muscular processes, with the involvement of nociceptors sensitive to chemical substances like those released from damaged or overloaded cells. Altered muscle metabolism and increased intramuscular levels of algesic substances have been observed in subjects with chronic neck and shoulder myalgia (Gold et al. 2017; Sjogaard et al. 2010). When investigating the causes of work-related neck and shoulder pain, several studies have focused on static muscle activations, as measured by EMG. However, previous research has found limited evidence of a causal association between work-related pain and muscle activation, as measured by EMG (Knardahl 2002; Larsson et al. 2008; Strøm et al. 2009a; Strøm et al. 2009b; Vasseljen and Westgaard 1996), and Knardahl (2002) has proposed a blood vessel–nociceptor interaction hypothesis in which muscle microcirculation is involved in the pathogenesis of musculoskeletal pain.

The association between TBF and neck pain in the present study indicates that muscle microcirculation and alternations in TBF may be involved in the pathogenesis of neck pain development, which is also consistent with previous studies (Gerdle et al. 2014; Knardahl 2002; Larsson et al. 2008; Larsson et al. 1999; Näslund et al. 2007; Rosendal et al. 2004; Sjogaard et al. 2010; Strøm et al. 2009b; Thorud et al. 2012). Strom et al. (2009b) showed significant correlations between neck pain and TBF during computer work for both subjects with chronic neck and shoulder pain and a healthy reference group; however, the associations were in opposite directions in the two groups. Higher TBF correlated with more neck pain for the pain group, whereas lower TBF correlated with more pain for the healthy group, contrary to the results in the present study.

It has also been previously reported that the amount of eyelid squinting (i.e. increased muscle activity in the orbicularis oculi) may be associated with TBF and neck pain during computer reading both under optimal lighting conditions and with exposure to glare (Mork et al. 2016). Eyelid squinting was positively related to neck pain, both with and without glare, whereas the relation to TBF was positive in the glare condition and negative in the optimal condition. The mechanisms behind the link between TBF and pain development are unclear and need further elucidation. However, muscle microcirculation is correlated with muscle metabolism, and different levels of metabolites involved in both pain sensation and vasodilation may explain the correlation between symptoms and circulation in both the present study and in previous research (Gerdle et al. 2014; Knardahl 2002; Sjøgaard et al. 2000; Strøm et al. 2009a; Strøm et al. 2009b).

There were also significant correlations between neck pain and several eye symptoms in the present study, which supports the notion of co-occurring neck and eye symptoms during visually demanding tasks (Hayes et al. 2007; Helland et al. 2008; Richter et al. 2011; Wiholm et al. 2007; Zetterberg et al. 2017). These associations were present in all conditions, suggesting symptom associations that are independent of exposure.

Furthermore, there were associations between neck pain and the experience of the lighting during exposure to both glare and psychological stress, indicating that the dual stress exposure affected the development of neck pain among participants; both visual and mental loads have previously been reported to be involved in neck pain development (Nilsen et al. 2007).

Positive and negative state moods

During exposure to psychological stress, participants reported a higher degree of overall negative state moods and perceived stress than they reported during computer work without psychological stress exposure. This indicates that the psychological stressors in the current study affected the participants while working by inducing a higher degree of negative feelings and stress, which is consistent with previous research (Skoluda et al. 2015).

Moreover, the more negatively a participant experienced the lighting during glare exposure, the more stress she felt. This indicates that excessive lighting from a glare source may influence how stressed some people feel, or vice versa. Psychological and/or biological effects due to handling one stressor might influence a person's ability to cope with another, coexisting stressor (Lepore and Evans 1996; Martimportugués-Goyenechea and Gómez-Jacinto 2005). The observed connection between perceived glare and stress in the present study might indicate that people's ability to cope with the visual stress made them feel more stressed, or vice versa. These results highlight the importance of preventing glare conditions during computer work and reveal that optimal lighting during computer work is important not only for visual comfort and avoiding symptom development but also for stress reduction and the general well-being of computer workers.

SUMMARY AND CONCLUSION

The main results from the present study are (1) glare exposure during computer work induced eye symptoms and increased feelings of being uncomfortable, with psychological stress exposure inducing negative state moods and perceived stress; (2) experience of the lighting during glare exposure was closely related to feelings of stress; (3) participants with high TBF reported more pronounced overall neck pain; and (4) associations between neck pain and eyestrain were present in all conditions.

These results reveal that symptom development during computer work is a complex matter, where the work task, environmental exposures, moods, and muscular changes are all apparently involved. Optimizing computer workstations are complex and several factors must be considered, including visual ergonomics, to promote comfort and well-being. Our results support international guidelines, and highlight proper lighting without glare as well as avoiding psychological stress. Moreover, computer work *per se*, even with optimal ergonomic adjustments, affects the workers. Further research is necessary to better understand the relationship between the different factors involved in symptom development during computer work.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest

The authors declare no conflict of interest.

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Ethical approval

The study protocol was approved by the Regional Committee for Medical and Health Research Ethics, Norway (2013/610), and followed the tenets of the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

All participants received verbal and written information about the study, and written informed consent was obtained from all participants.

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Figure 1 is made in SPSS

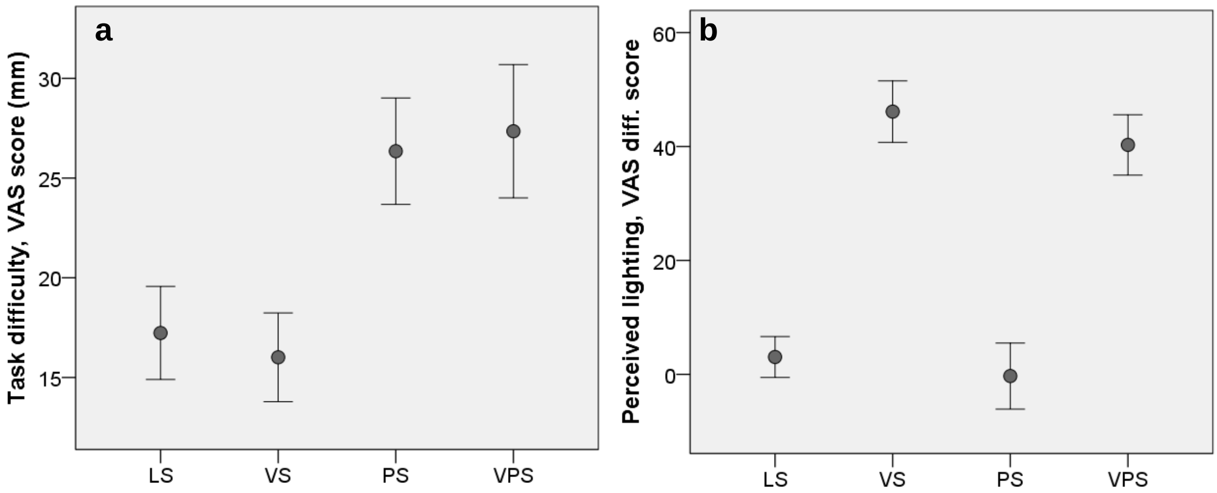

Fig. 1 Scores for (a) how difficult the participants found the task during the four computer work sessions (n = 43), and (b) perceived lighting at the workstation given as differential scores (perceived lighting during computer work – score before start of work) for each condition (n = 20); LS = low stress, VS = visual stress, PS = psychological stress, VPS = visual and psychological stress. A higher score indicates that the task was perceived as more difficult or the lighting was perceived as worse compared to rest. Results are given as mean mm VAS ± SEM. The exact (not the differential) scores for perceived lighting during computer work (n = 43) have previously been reported (Mork et al. 2018).

Figure 2 is made in SPSS

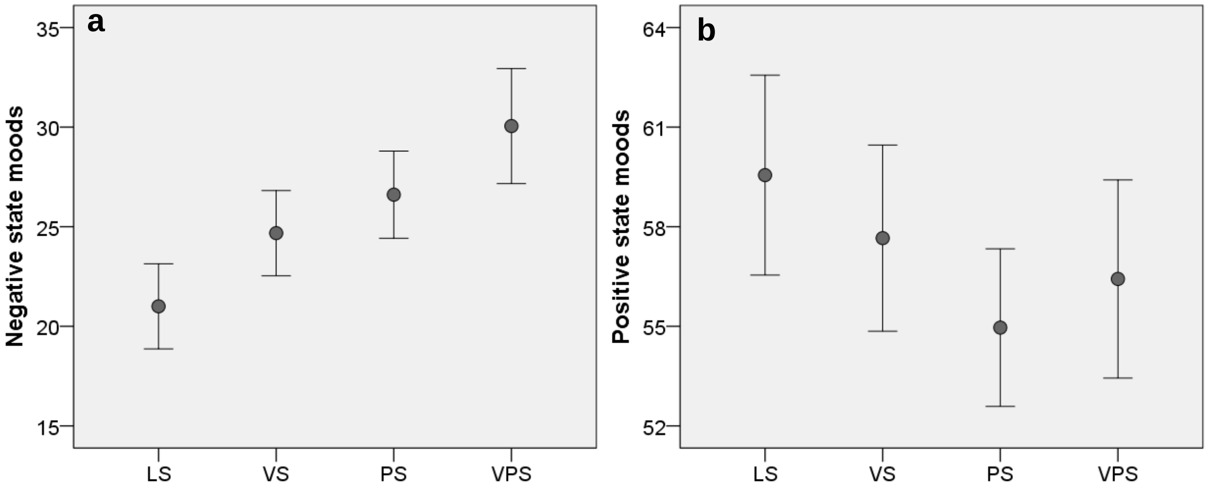

Fig. 2 Self-reported negative state moods (stressed, strained, uncomfortable and bored) and positive state moods (satisfied, relaxed and concentrated) during the four conditions: LS = low stress, VS = visual stress, PS = psychological stress, VPS = visual and psychological stress. Results are given as mean mm VAS ± SEM from the included state moods (n = 43). Higher scores indicate more total reported negative or positive moods.

Figure 3 is made in SPSS

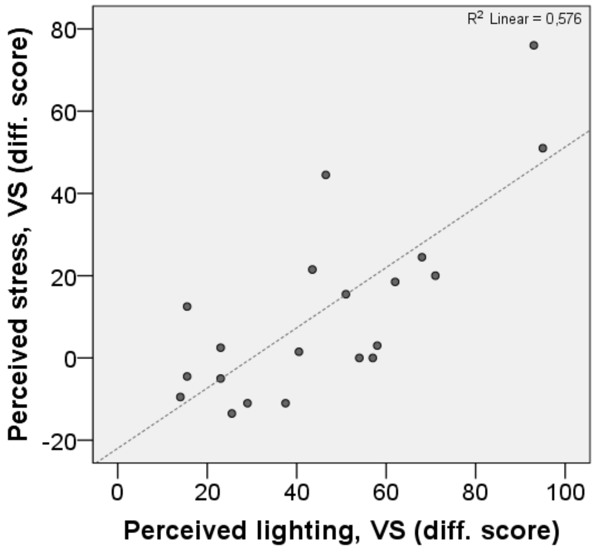

Fig. 3 Correlation plot showing the association between perceived lighting and stress during computer work with glare exposure only (VS= visual stress). The scores are given as differential VAS score (mm VAS score during computer work – score in the rest session before start).

Table 1 is made in Word 2013

Table 1. Overview of the questionnaire (subjective symptoms, positive and negative state moods, and additional questions), and the main group (positive or negative) into which the state moods were categorized.

Subjective symptoms	
Pain or discomfort in the neck (*neck pain*) [1, 2]	
Pain or discomfort in the shoulders (*shoulder pain*) [1, 2]	
General tiredness in and around the eyes (*eye-related tiredness*) [1, 2]	
Pain in and around the eyes (*eye pain*) [1, 2]	
Photophobia [2]	
Dry eyes [2]	
Head tiredness [2]	
Headache [2]	
Blurred vision [2]	
Positive and negative state moods	**Main group**
Strained [1, 2]	Negative
Stressed [1, 2]	Negative
Uncomfortable [1b, 2]	Negative
Bored [1b, 2]	Negative
Satisfied [1b, 2]	Positive
Relaxed [1, 2]	Positive
Concentrated [1b, 2]	Positive
Other questions	
Perceived difficulty of the computer task [1, 2]	
Perceived workstation lighting [1b, 2]	

[1,2] Question registered in 2015 (1) and/or 2016 (2), both before and after the computer work conditions.
[1b] Question registered only after the computer work conditions in 2015.

Table 2 is made in Word 2013

Table 2. Self-reported positive and negative trait affect (each rated from 1 to 5). Results are given as mean ± SEM, and as a range.

	Mean (n)	Range	Index
Active	3.2 (43)	1–5	Positive
Watchful	2.3 (43)	1–5	Positive
Inspired	3.1 (42)	2–5	Positive
Determined	3.6 (43)	1–5	Positive
Attentive	3.7 (43)	2–5	Positive
Indignant	1.7 (43)	1–4	Negative
Shameful	1.4 (43)	1–4	Negative
Nervous	2.2 (43)	1–5	Negative
Unfriendly	1.3 (43)	1–3	Negative
Scared	1.7 (43)	1–4	Negative
Positive personality traits (sum positive)	15.8 (42)	9–21	(max 25)
Negative personality traits (sum negative)	8.2 (43)	5–15	(max 25)

Table 3 is made in Word 2013

Table 3. Self-reported symptoms before (*rest*) and immediately after (*after*) the four computer work conditions.

	LS		VS		PS		VPS	
Subjective symptoms (n)	rest	after	rest	after	rest	after	rest	after
Eye-related tiredness (41)# G	28.1 ± 3.8	28.7 ± 3.6	27.5 ± 3.4	39.8 ± 3.9G	29.5 ± 3.7	33.7 ± 3.8	25.6 ± 3.4	36.3 ± 3.8G
Eye pain (41)#	9.6 ± 2.6	14.0 ± 3.3	5.5 ± 1.6	13.1 ± 2.9	4.7 ± 1.4	11.2 ± 3.1	7.0 ± 2.3	14.1 ± 3.1
Neck pain (41)#	10.3 ± 2.3	13.2 ± 2.2	7.0 ± 1.5	13.1 ± 2.5	9.3 ± 2.3	11.1 ± 2.5	11.5 ± 2.3	13.7 ± 2.3
Shoulder pain (41)	14.6 ± 3.1	14.2 ± 3.4	10.2 ± 2.1	11.4 ± 2.2	9.7 ± 2.5	12.6 ± 2.6	9.8 ± 2.3	13.3 ± 3.1
Headache (20)	13.4 ± 4.0	12.8 ± 4.2	7.4 ± 2.8	11.7 ± 3.9	9.6 ± 3.3	15.7 ± 4.5	13.7 ± 4.2	15.0 ± 4.6
Head tiredness (20)G	20.8 ± 3.8	19.7 ± 3.8	19.4 ± 4.9	24.6 ± 5.0G	24.5 ± 5.0	28.9 ± 5.9	21.3 ± 5.0	25.9 ± 5.4G
Blurred vision (20)#	3.2 ± 1.6	5.8 ± 2.5	2.8 ± 1.4	7.4 ± 3.4	3.6 ± 1.4	6.6 ± 2.1	2.7 ± 1.9	6.2 ± 2.6
Photophobia (20)# G	2.3 ± 0.9	4.6 ± 1.9	3.9 ± 2.3	18.7 ± 4.4G	5.4 ± 2.1	5.0 ± 2.1	3.4 ± 1.1	14.9 ± 4.0G
Dry eyes (20)	15.8 ± 4.5	21.4 ± 5.1	18.4 ± 5.1	25.0 ± 6.8	20.1 ± 5.3	24.7 ± 6.3	20.8 ± 5.6	24.5 ± 6.7
Eye symptoms, mean (41)# G	17.8 ± 2.5	21.7 ± 2.9	16.1 ± 2.0	26.2 ± 2.6G	16.9 ± 2.1	22.4 ± 2.7	15.3 ± 2.1	24.1 ± 2.5G

LS = low stress, VS = visual stress, PS = psychological stress, VPS = visual and psychological stress. Results are given as mean mm VAS ± SEM. #main effect of time; G interaction effect between glare and time for the specific symptom (exposure*time).

Table 4 is made in Word 2013

Table 4. Self-reported state moods before (*rest*) and during the computer-work conditions (*work*).

	LS		VS		PS		VPS	
state moods (n)	rest	work	rest	work	rest	work	rest	work
Stressed (42)$^{\# \, P}$	10.1 ± 1.8	17.9 ± 2.7	10.4 ± 1.8	19.4 ± 2.9	9.8 ± 2.3	33.6 ± 3.4^{P}	11.0 ± 2.1	32.6 ± 3.8^{P}
Strained (42)$^{\#}$	15.9 ± 2.7	23.4 ± 3.3	12.4 ± 1.8	25.7 ± 3.2	12.6 ± 1.7	28.0 ± 3.1	14.4 ± 2.3	32.5 ± 4.0
Relaxed (42)$^{\#}$	72.7 ± 4.0	63.6 ± 4.1	76.0 ± 3.5	63.5 ± 3.5	73.2 ± 3.6	56.6 ± 3.9	72.8 ± 3.9	59.8 ± 4.1
Uncomfortable (43)^{G}		17.5 ± 2.7		26.2 ± 3.3^{G}		19.5 ± 2.9		30.4 ± 4.2^{G}
Concentrated (43)		62.0 ± 3.9		60.9 ± 3.7		62.0 ± 3.3		63.0 ± 4.0
Satisfied (43)		52.9 ± 3.9		48.4 ± 3.3		46.1 ± 3.3		47.4 ± 3.9
Bored (43)		25.2 ± 3.6		27.5 ± 3.5		25.5 ± 3.3		25.5 ± 3.5

LS = low stress, VS = visual stress, PS = psychological stress, VPS = visual and psychological stress. Results are given as mean mm VAS ± SEM. $^{\#}$main effect of time; $^{G}/^{P}$ interaction effect between glare (G) or psychological stress (P) and time for the specific symptom (exposure*time)

Table 5 is made in Word 2013

Table 5
Average score (mm VAS) for reported neck pain in the participants with Low and High trapezius muscle blood flow (TBF) during the computer work conditions.

Symptom	Condition	p-value	t	Low TBF (n = 15)	High TBF (n = 17)
Neck pain	LS	.083	-1.79	8.0 ± 2.6	18.6 ± 3.9
	VS	.008	-2.85	7.1 ± 3.7	19.2 ± 4.0*
	PS	.037	-2.18	5.8 ± 2.8	16.3 ± 4.6*
	VPS	.011	-2.70	7.7 ± 3.0	21.3 ± 3.8*

LS = low stress, VS = visual stress, PS = psychological stress, VPS = visual and psychological stress.
Results are given as mean mm VAS ± SEM. *Statistically significant difference between the groups at $p < 0.05$.

Table 6 is made in Word 2013

Table 6. Correlations between neck pain and eye and visual symptoms (mm VAS) in the four computer work conditions.

	Neck pain			
	LS	VS	PS	VPS
Eye tiredness (43)	.452**	.424**	.486**	.437**
Eye pain (43)	.498**	.487**	.560**	.490**
Dry eyes (20)	.369	.546*	.515*	.437(*)
Eye symptoms, total (43)	.508**	.489**	.563**	.480**
Experience of lighting (43)	.089	.139	.055	.357*

LS = low stress, VS = visual stress, PS = psychological stress, VPS = visual and psychological stress. Results are given as Pearson's correlation coefficients. */**Statistically significant correlation at $p < 0.05$ and 0.01, respectively. (*)Borderline but not statistically significant correlation ($p \leq .060$)