

31 **ABSTRACT**

32 **Purpose**

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

39 **Methods**

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

49 **Results**

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

56 **Conclusions**

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

63

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

65

66 INTRODUCTION

67 Computer workers generally report a high prevalence of musculoskeletal pain. The symptoms
68 most frequently reported are pain or discomfort in the neck and shoulder area (Kalinienė et al.
69 2016; Larsson et al. 2007; Mohanty et al. 2017; Woods 2005). Already in the 1700's, Ramazzini
70 realized that musculoskeletal pain were associated with ergonomic factors (Piccoli 2003), and
71 later Duke-Elder found an association between occupational near work and visual symptoms
72 (Duke-Elder 1930). Near work, such as computer work, is visually demanding as several eye
73 muscles are involved in keeping a near object clearly focused and single (Lie et al. 2000; Lie
74 and Watten 1994). The ciliary muscle around the lens contracts to focus the object
75 (accommodation), the extraocular muscles move the eyes medially (convergence), and the iris
76 sphincter muscle reduces the pupil size (miosis) (Atchison and Smith 2000). Furthermore,
77 blink rate is reported to decrease, inducing dry eyes (Rosenfield 2011; Skotte et al. 2007;
78 Wolkoff 2008). Consequently, visual discomfort, tired and uncomfortable eyes, blurred vision
79 and headache develop during computer work (Aarås et al. 2005; Rosenfield 2011; Wolkoff et
80 al. 2005; Woods 2005).

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

93 Poor visual conditions during computer work, like glare exposure, may also contribute to pain
94 development (Blehm et al. 2005; Gowrisankaran et al. 2007; Mork et al. 2016; Nahar et al. 2007).
95 The two most common forms of glare are disability glare and discomfort glare. Disability glare
96 occurs when a reduction in visual performance caused by light scattered in the ocular media
97 is present and results in reduced contrast and visibility in the field of view (Vos 2003).
98 Discomfort glare refers to the sensation of visual annoyance and distraction because of high
99 luminance or high luminance contrasts within the visual field (Mainster and Turner 2012; Vos
100 2003).

101 In addition, glare exposure has been reported to result in increased orbicularis oculi muscle
102 activity and decreased aperture size (eyelid squinting), decreased pupil size, increased
103 trapezius blood flow, altered eye movements, decreased reading performance, and reduced
104 productivity (Berman et al. 1994; Glimne et al. 2015; Glimne et al. 2013; Gowrisankaran et al.
105 2007; Hemphälä and Eklund 2012; Lin et al. 2015; Mork et al. 2016; Mork et al. 2018).

106 Several factors have been proposed to contribute to computer-related neck pain development,
107 including posture, duration of computer work, psychological stress, repetitive movements,
108 prolonged static loads, and psychosocial effects of the work environment (da Costa and Vieira
109 2010; Gerr et al. 2004; Hagberg 1984; Jun et al. 2017; Larsson et al. 2007; Linton 2000; van der
110 Windt et al. 2000; Wahlström 2005). The association between psychosocial factors and
111 musculoskeletal pain has been linked to stress and attention-related muscle activity.
112 Electromyography (EMG) studies have shown that situations that demand continued
113 attention elicit low-level muscle activity in the trapezius muscle and in other muscles. The
114 muscle activity appears to have no relation to any biomechanical demands arising from the
115 work task itself (Wærsted 2000; Wærsted et al. 1996). This muscle activity may be linked to
116 increased autonomic and cortical arousal found in the physiological stress response. Findings
117 showing that the same motor units appear to be activated by both mental and physical loads
118 (Lundberg et al. 2002), lend additional support to this notion.

119 Individual differences may represent an additional challenge to the understanding of pain and
120 discomfort associated with computer work. It is known that different personalities have
121 different autonomic reactions to acute psychological stressors (Chida and Hamer 2008;
122 Jonassaint et al. 2009). Dispositional tendencies to experience negative emotions, often called
123 negative affect, may be of special interest in this regard. Trait negative affect is known to
124 influence somatic complaints, perceived stress, depressive symptoms, and fatigue (Denollet
125 and De Vries 2006; Spink et al. 2018). In addition, trait negative affect is associated with
126 increased autonomic arousal and thus the physiological stress response itself (Kehoe et al.
127 2013; Kreibig 2010). However, research also indicates that transient emotions, often called state
128 emotions or moods, are important in the understanding of stress in the workplace. Stress
129 increases the activation of the hypothalamic–pituitary–adrenal (HPA) axis, with increased
130 secretion of cortisol as a result. Increased cortisol levels appear to influence mood by
131 regulating feelings of arousal and affect during and after stressful events (Het and Wolf 2007;
132 Kuhlmann et al. 2005). Furthermore, studies indicate that mood is influenced by
133 environmental factors. Research by Veitch et al. (2013), reports that mood mediates the effect
134 of lighting appraisals on important work-related variables such as job engagement and well-
135 being. This result accords with Wahlström’s (2005) explanation of the development of pain
136 and discomfort during computer work as a complex interaction between the individual’s
137 physical and psychological demands and the work organization.

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

144 **METHODS**

145 **Subjects**

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

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

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

165 **Laboratory set-up and design**

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

175 The laboratory experiment had a counterbalanced, fully factorial, repeated 2x2x4 design. The
176 computer task in all four conditions was to read a text on a computer screen, identify spelling
177 errors in the text, and mark these errors in bold using a standard wireless laser mouse as a
178 pointing device. All four computer work conditions consisted of the same parts: (1) a one-
179 minute rest session before computer work (*rest*), (2) ten minutes of computer work, (3) a break
180 (13.9 ± 2.1 min, mean \pm SD, $n = 43$), and (4) a one-minute rest session after the break to measure
181 recovery (*recovery*). The recovery session after one condition was concurrent with the rest
182 session before the next condition. In each condition, the participants performed the same
183 computer task, but were exposed to different stress requirements, as listed below:

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

186 2. Visual stress (VS): Exposure to direct glare from two large luminaires placed behind the
187 computer screen simulating a window in an office. The luminance of the glare source was 4634
188 ± 749 cd/m² (mean \pm SD) measured across the luminaire screens. The glare source simulated a
189 window placed behind the computer screen, and the luminance levels was close to that from
190 a window on an overcast day.

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

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

201 The luminance levels during LS and PS (with the glare source turned off) were within the
202 luminance ratio of 5:3:1 recommended for a computer work context (Anshel 2007; Piccoli 2003).
203 The luminance was 155 cd/m² in the working field (computer screen turned on), 90 cd/m² in
204 the immediately surrounding area (desktop area closest to computer screen) and 61 cd/m² in
205 the background area (the wall behind the glare source and peripheral parts of the desktop).
206 During VS and VPS with the glare source turned on, the luminance ratio was 1:3:30 (155 cd/m²:
207 520 cd/m²: 4634 cd/m²). A Hagner Universal Photometer (Modell S4, Sweden) was used for the
208 luminance measurements, and values are the average luminance measured from the
209 participant's eye during testing towards several different measure points across the glare
210 source surface. (For further details, see Mork et al., 2018).

211 **Measurements**

212 The participants completed a questionnaire immediately after the rest recording, before the
213 start of the 10-minute computer work period, and another questionnaire immediately after the
214 computer work period for each of the four conditions. These questionnaires consisted of
215 questions with 100 mm Visual Analogue Scales (VAS) (Kildeso et al. 1999); the participants
216 were asked to rate the degree to which they experienced different subjective symptoms, the
217 extent to which they felt different positive and negative state moods, and how they perceived
218 the workstation lighting and task difficulty. The left end-points (0 mm) on the scales
219 represented 'nothing', whereas the right end-point (100 mm) represented 'very much'. Table
220 1 provides an overview of the questionnaire and a grouping of the state moods. Because of an
221 observed necessity for supplementary information about symptoms and moods, some
222 questions were added during the 2016 test period.

223 *Subjective symptoms*

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

227

228 *Table 1 approximately here.*

229

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

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

237 *Negative and positive state moods*

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

247 *Perceived workstation lighting and task difficulty*

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

252 *Trait affect*

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

259

260 *Table 2 approximately here.*

261 *Neck pain and trapezius muscle blood flow*

262 The data in this article are part of a larger study, which also included measurement of
263 physiological parameters such as trapezius muscle blood flow and presented in Mork et al.
264 (2018). To investigate the associations between muscle blood flow in the trapezius and neck
265 pain, the participants were divided into two subgroups regarding average trapezius muscle
266 blood flow (TBF) during the four computer work conditions. The subgroups were: (1) *High*
267 *TBF*: participants with TBF equal to or higher than the median value ($n = 17$) and (2) *Low TBF*:
268 participants with TBF measurements lower than the median value ($n = 15$).

269

270 **Statistics**

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

282

283 **RESULTS**

284 **Trait affect**

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

289

290 **Visual and psychological stress on perceived task difficulty and ambient lighting**

291 Figure 1a shows that the participants experienced the task as significantly more difficult in the
292 two conditions with psychological stress than conditions without psychological stress: $F(1.0,$
293 $42.0) = 15.17, p < .000, \eta^2 = .27$). Glare exposure (visual stress), however, affected the perceived
294 workstation lighting negatively, as there was a glare-by-time interaction: $F(1.0, 19.0) = 40.85,$
295 $p < .000, \eta^2 = .68$). Figure 1b shows the differential score for how the participants perceived the
296 ambient lighting.

297

Figure 1 approximately here.

298

299 **Subjective symptoms**

300 *Main effects of visual and psychological stress exposure*

301 Table 3 shows self-reported symptoms for each computer-work condition. The analysis
302 revealed a significant glare-by-time interaction for total eye symptoms: $F(1.00, 40.00) = 6.13, p$
303 $= .018, \eta^2 = .13$. Furthermore, there were significant glare-by-time interactions for eye-related
304 tiredness: $F(1.00, 40.00) = 9.29, p = .004, \eta^2 = .19$; for head tiredness: $F(1.00, 19.00) = 5.16, p = .035,$
305 $\eta^2 = .21$; and for photophobia: $F(1, 19) = 13.24, p = .002, \eta^2 = .41$. These results indicate that glare
306 exposure led to increased eyestrain and visual discomfort during computer work.

307

308

Table 3 approximately here.

309

310 *Time effects*

311 The results further showed a main effect of time for total eye symptoms: $F(1,40) = 33.87, p <$
312 $.001, \eta^2 = .46$. Among individual symptoms, time effects were also seen for eye-related
313 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:
314 $F(1, 40) = 27.15, p < .001, \eta^2 = .40$; blurry vision: $F(1, 19) = 10.44, p = .004, \eta^2 = .36$; head tiredness:
315 $F(1, 19) = 6.50, p = .020, \eta^2 = .26$; and photophobia: $F(1, 19) = 23.99, p < .001, \eta^2 = .56$ (Table 3).
316 This suggests that the symptoms increased with time, independent of condition and exposure.

317

318 **Positive and negative state moods**

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

322

323

Figure 2 approximately here.

324

325 *Main effect of visual and psychological stress exposure*

326 The results showed a significant main effect of psychological stress for negative state moods:
327 $F(1.00, 42.00) = 12.69, p = .001, \eta^2 = .23$, indicating that participants reported more negative
328 moods due to psychological stress exposure (Figure 2a). There was no significant effect of
329 exposure to either glare or psychological stress for positive state moods (Figure 2b).

330 Analysis revealed a significant glare-by-time interaction for feeling uncomfortable: $F(1.00,$
331 $40.00) = 9.29, p = .004, \eta^2 = .19$; and a significant psychological stress-by-time interaction for

332 perceived stress: $F(1.00, 41.00) = 13.23, p = .001, \eta^2 = .24$, indicating that visual and
333 psychological stresses induced different negative moods during computer work.

334 *Time effects*

335 The results also showed a main effect of time for perceived stress: $F(1, 41) = 71.90, p < .001, \eta^2 =$
336 $.64$; feeling strained: $F(1, 41) = 43.98, p < .001, \eta^2 = .52$; and relaxed: $F(1, 41) = 17.92, p < .001, \eta^2 =$
337 $.30$. This reflects the fact participants were more stressed and strained and less relaxed at the
338 end of the computer work than before the start in all conditions, independent of the induced
339 stress requirements.

340

341

Table 4 approximately here.

342

343 **Trapezius muscle blood flow and neck pain**

344 Table 5 shows that participants with high TBF levels during computer work reported more
345 neck pain in conditions with glare and/or psychological stress, than participants with low TBF.
346 There was no significant difference in posture between these two subgroups, except for head
347 angle in the LS condition, during which the high TBF group showed slightly less flexion ($3.5 \pm$
348 1.7 degrees vs 5.0 ± 2.5 degrees, $p = .039$).

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

351

352

Table 5 approximately here.

353

354 **Correlation analyses**

355 *Neck pain associations*

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

358

Table 6 approximately here.

359

360 *Associations between perceived lighting and stress during glare exposure*

361 There were positive correlations between perceived lighting and the development of stress
362 (differential scores: during work – before start) when exposed to glare in VS ($r = 0.737, p <$
363 0.001) and in VPS ($r = 0.494, p = 0.027$). Figure 3 shows this association during exposure to
364 glare only (in VS). This indicates that perceiving the workstation lighting as unpleasant
365 during computer work with glare exposure was related to increased feelings of stress or
366 vice versa.

367

368

Figure 3 approximately here.

369 **Test session order**

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

382 **DISCUSSION**

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

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

405 **Subjective symptoms**

406 *Main effects of visual and psychological stress exposure*

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

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

420 High visual demands and increased load on intra- and extraocular muscles, such as stress on
421 the accommodative–convergence system, are assumed to be involved in the development of
422 eye symptoms (Bruenech and Kjellefold Haugen 2007; Sheedy et al. 2003a; Zetterberg et al.
423 2017). Regarding glare conditions, glare exposure have been reported to put extra load on the
424 visual system by affecting accommodation (Shahnavaz and Hedman 1984; Wolska and
425 Switula 1999), the binocular coordination (Glimne et al. 2013), eye movements (Glimne et al.
426 2015; Lin et al. 2015), and the iris muscle’s regulation of pupil size (Fry and King 1975;
427 Hopkinson 1956). Therefore, intra and extraocular muscle strain may also be involved in the
428 glare-induced eyestrain and discomfort observed here.

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

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

440 *Time effects*

441 There were significant time effects in the present study for both eye symptoms and neck
442 symptoms, indicating a significant increase in general symptoms during computer work
443 compared to rest, independent of exposure. This supports the notion that working on a
444 computer screen is associated *per se* with the development of neck symptoms and eye

445 discomfort (Blehm et al. 2005; Duke-Elder 1930; Köpper et al. 2016; Mork et al. 2016). Prolonged
446 computer work requires sustained activation of intra- and extra ocular eye muscles involved
447 in the near response (e.g. accommodation, convergence, miosis). This has been found to be
448 associated with eyestrain development (Blehm et al. 2005; Bruenech and Kjellevold Haugen
449 2007; Jaschinski-Kruza 1991; Mork et al. 2016).

450 The increase in eyestrain during computer work *per se* may also have been influenced by other
451 risk factors present during computer work, such as attention-decreased blinking, increased
452 amounts of incomplete blinks, and a higher gaze angle compared to reading hard copy text
453 with depressed gaze. These factors may contribute to increased corneal exposure and inducing
454 symptoms such as dry and irritated eyes (Rosenfield 2011; Wolkoff 2008). However, no
455 significant increase in dry eye symptoms was found in the present study. The computer tasks
456 were short in duration and were possibly not sufficiently lengthy to affect self-perceived dry
457 eye levels. Furthermore, corneal exposure and incomplete blinks were not measured, and we
458 cannot elucidate how these factors were involved in the eyestrain observed increase during all
459 conditions. Köpper et al. (2016) showed that placing the screen and the hard copy text in a
460 similar paper-like gaze position eliminated the differences in reported eyestrain during
461 reading on a computer screen compared to hard copy reading. This supports previous findings
462 that show beneficial effects on the visual system, visual symptoms, and musculoskeletal
463 symptoms of lower gaze angles during computer work (Fostervold 2003; Fostervold et al.
464 2006) and points out the importance of optimal gaze angle in preventing discomfort during
465 computer work. Further, it should be mentioned that adverse chemical, physical and biological
466 agents in the indoor environment might also cause eye symptoms (Piccoli 2003). In our study,
467 air temperature and humidity were measured during testing periods to ensure a stable lab
468 environment. However, as environmental agents were not measured, we cannot totally
469 exclude any potential influence on the time effects found in this study, but this is most likely
470 negligible.

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

484 **Neck pain and trapezius blood flow**

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

501 The association between TBF and neck pain in the present study indicates that muscle
502 microcirculation and alternations in TBF may be involved in the pathogenesis of neck pain
503 development, which is also consistent with previous studies (Gerdle et al. 2014; Knardahl 2002;
504 Larsson et al. 2008; Larsson et al. 1999; Näslund et al. 2007; Rosendal et al. 2004; Sjøgaard et al.
505 2010; Strøm et al. 2009b; Thorud et al. 2012). Strøm et al. (2009b) showed significant correlations
506 between neck pain and TBF during computer work for both subjects with chronic neck and
507 shoulder pain and a healthy reference group; however, the associations were in opposite
508 directions in the two groups. Higher TBF correlated with more neck pain for the pain group,
509 whereas lower TBF correlated with more pain for the healthy group, contrary to the results in
510 the present study.

511 It has also been previously reported that the amount of eyelid squinting (i.e. increased muscle
512 activity in the orbicularis oculi) may be associated with TBF and neck pain during computer
513 reading both under optimal lighting conditions and with exposure to glare (Mork et al. 2016).
514 Eyelid squinting was positively related to neck pain, both with and without glare, whereas the
515 relation to TBF was positive in the glare condition and negative in the optimal condition. The
516 mechanisms behind the link between TBF and pain development are unclear and need further
517 elucidation. However, muscle microcirculation is correlated with muscle metabolism, and
518 different levels of metabolites involved in both pain sensation and vasodilation may explain
519 the correlation between symptoms and circulation in both the present study and in previous
520 research (Gerdle et al. 2014; Knardahl 2002; Sjøgaard et al. 2000; Strøm et al. 2009a; Strøm et al.
521 2009b).

522 There were also significant correlations between neck pain and several eye symptoms in the
523 present study, which supports the notion of co-occurring neck and eye symptoms during
524 visually demanding tasks (Hayes et al. 2007; Helland et al. 2008; Richter et al. 2011; Wiholm et

525 al. 2007; Zetterberg et al. 2017). These associations were present in all conditions, suggesting
526 symptom associations that are independent of exposure.

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

531

532 **Positive and negative state moods**

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

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

549

550 **SUMMARY AND CONCLUSION**

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

557 These results reveal that symptom development during computer work is a complex matter,
558 where the work task, environmental exposures, moods, and muscular changes are all
559 apparently involved. Optimizing computer workstations are complex and several factors must
560 be considered, including visual ergonomics, to promote comfort and well-being. Our results
561 support international guidelines, and highlight proper lighting without glare as well as

562 avoiding psychological stress. Moreover, computer work *per se*, even with optimal ergonomic
563 adjustments, affects the workers. Further research is necessary to better understand the
564 relationship between the different factors involved in symptom development during
565 computer work.

566

567

568 **COMPLIANCE WITH ETHICAL STANDARDS**

569

570 **Conflict of interest**

571 The authors declare no conflict of interest.

572

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577

578 **Ethical approval**

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

582

583 **Informed consent**

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

586

587

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834

Figure 1 is made in SPSS

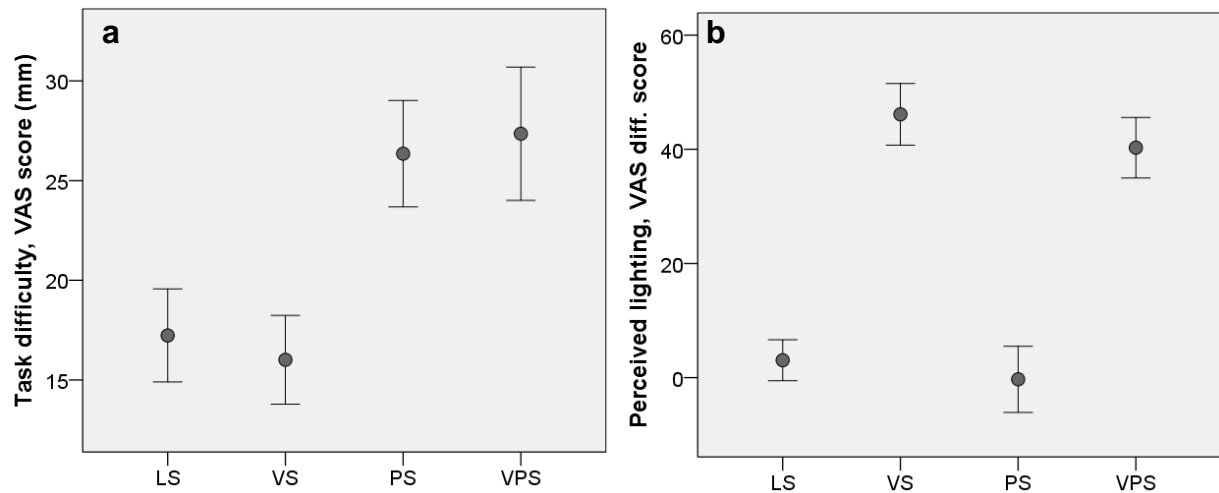


Fig. 1 Scores for (a) how difficult the participants found the task during the four computer work sessions ($n = 43$), and (b) perceived lighting at the workstation given as differential scores (perceived lighting during computer work – score before start of work) for each condition ($n = 20$); LS = 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 \pm 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

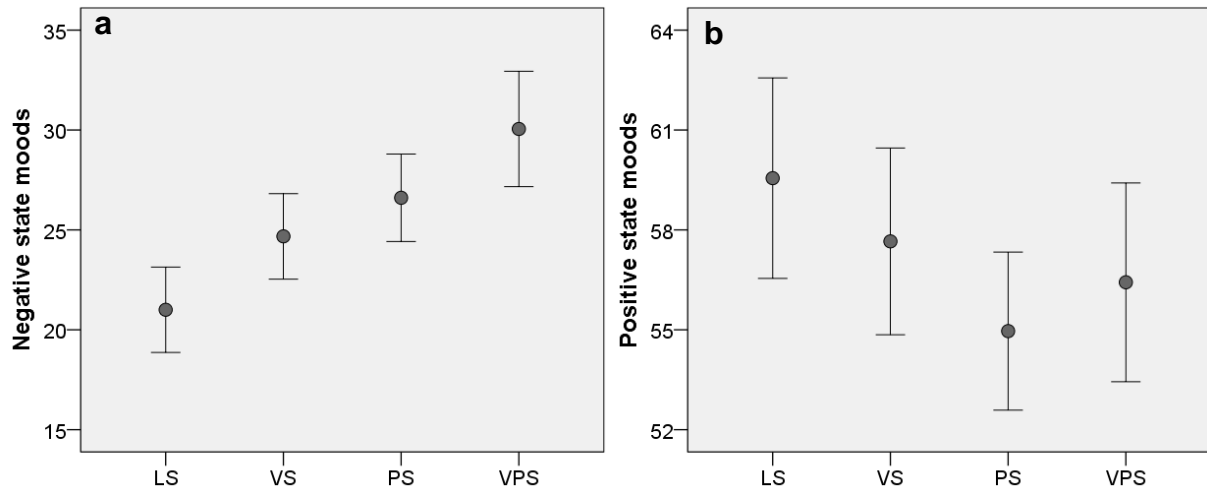


Fig. 2 Self-reported negative state moods (stressed, strained, uncomfortable and bored) and positive state moods (satisfied, relaxed and concentrated) during the four conditions: LS = low stress, VS = visual stress, PS = psychological stress, VPS = visual and psychological stress. Results are given as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

Figure 3 is made in SPSS

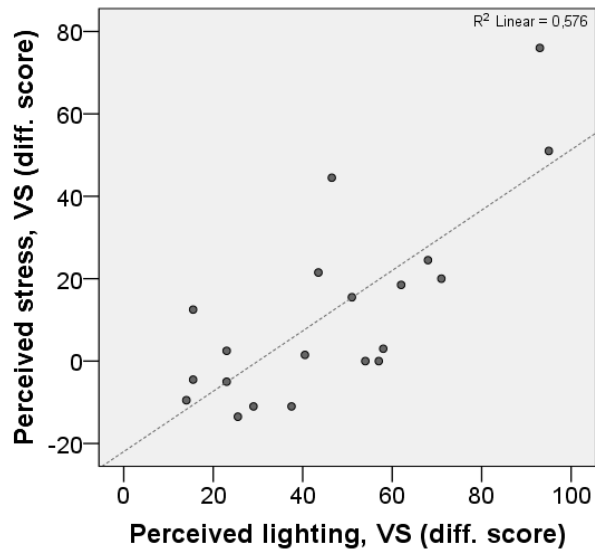


Fig. 3 Correlation plot showing the association between perceived lighting and stress during computer work with glare exposure only (VS= visual stress). The scores are given as differential VAS score (mm VAS score during computer work – score in the rest session before start).

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 (<i>neck pain</i>) ^{1,2}	
Pain or discomfort in the shoulders (<i>shoulder pain</i>) ^{1,2}	
General tiredness in and around the eyes (<i>eye-related tiredness</i>) ^{1,2}	
Pain in and around the eyes (<i>eye pain</i>) ^{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 \pm 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.

Subjective symptoms (n)	LS		VS		PS		VPS	
	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 ± 3.9 ^G	29.5 ± 3.7	33.7 ± 3.8	25.6 ± 3.4	36.3 ± 3.8 ^G
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 ± 5.0 ^G	24.5 ± 5.0	28.9 ± 5.9	21.3 ± 5.0	25.9 ± 5.4 ^G
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 ± 4.4 ^G	5.4 ± 2.1	5.0 ± 2.1	3.4 ± 1.1	14.9 ± 4.0 ^G
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 ± 2.6 ^G	16.9 ± 2.1	22.4 ± 2.7	15.3 ± 2.1	24.1 ± 2.5 ^G

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*).

<i>state moods (n)</i>	LS		VS		PS		VPS	
	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 ($p \leq .060$)