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Effects of visually demanding near work on trapezius muscle activity

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\textbf{A B S T R A C T}

Poor visual ergonomics is associated with visual and neck/shoulder discomfort, but the relation between visual demands and neck/shoulder muscle activity is unclear. The aims of this study were to investigate whether trapezius muscle activity was affected by: (i) eye-lens accommodation; (ii) incongruence between accommodation and convergence; and (iii) presence of neck/shoulder discomfort. Sixty-six participants (33 controls and 33 with neck pain) performed visually demanding near work under four different trial-lens conditions. Results showed that eye-lens accommodation per se did not affect trapezius muscle activity significantly. However, when incongruence between accommodation and convergence was present, a significant positive relationship between eye-lens accommodation and trapezius muscle activity was found. There were no significant group-differences. It was concluded that incongruence between accommodation and convergence is an important factor in the relation between visually demanding near work and trapezius muscle activity. The relatively low demands on accommodation and convergence in the present study imply that visually demanding near work may contribute to increased muscle activity, and over time to the development of near work related neck/shoulder discomfort.

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1. Introduction

Poor visual ergonomics, such as inadequate lighting, debilitating glare, incorrect eyeglass correction, close viewing distance, demanding 3-D viewing, full time microscopy, or long periods of work without breaks, increase visual discomfort (Blehm et al., 2005; Kreczy et al., 1999; Wee et al., 2012; Wolkoff et al., 2012; Yan et al., 2008). Visual discomfort is a common symptom among professional users of information technology, and has also been linked to neck/shoulder discomfort, which is another common concurrent complaint (Bhandari et al., 2008; Cagnie et al., 2007; Helland et al., 2008; Richter et al., 2011b; Robertson et al., 2013; Rosenfeld, 2011; Wiholm et al., 2007; Woods, 2005).

To bring an object (e.g., a computer screen or a smart phone) at a near distance into clear focus and single vision requires three mechanisms in the eye to work together: (1) an increase in the optical power of the eye-lens (eye-lens accommodation), (2) an inward movement of the eyes (convergence), and (3) a change in pupil size. Eye-lens accommodation enables a clear image from objects at different distances, and is achieved by activity in the ciliary muscles. Convergence is necessary to maintain single vision during normal binocular viewing (i.e., viewing with both eyes), and is controlled by the extra ocular muscles. The size of the pupil changes the depth of focus, and is controlled by the iris (Kaufman et al., 2003). Under normal viewing conditions, accommodation and convergence are synergistically coupled. When a blurred object is brought into focus, both accommodation and convergence are active to counteract the blurred image. Similarly, both convergence and accommodation counteract double vision. (Miles et al., 1987). The process of keeping a close object in focus is only possible if the eyes are stationary with respect to the object in focus. The vestibulo-ocular reflex is an important mechanism to keep the gaze stable. If, for example, the head is turned to the right, the reflex causes the eyes to move to the left, in order to keep the gaze stable at the object in focus (Kaufman et al., 2003).

A possible explanation for the link between visual discomfort and neck/shoulder discomfort is a tightly coordinated relationship between eye and neck/shoulder muscles to stabilize gaze (Bizzzi et al., 1971; Corneil et al., 2008; Richter et al., 2011a; Tu and Keating, 2000). Such a relationship is perhaps most evident when the vestibulo-ocular reflex produces an eye-movement in the opposite direction to a head movement. The vestibulo-ocular reflex is predominantly a vision stabilizer that activates extra-ocular muscles (Brandt and Dieterich, 1999; Wurtz, 2008). However, whether there is a reflex or physiological mechanism which acts in the opposite direction, that is increasing activity in head and
neck stabilizing muscles in response to visually demanding tasks, is unclear (Richter et al., 2011a; Richter and Forsman, 2011). At present, the support for a relationship between visual demands and neck/shoulder muscle activity during visually demanding near work is inconclusive (Brewer et al., 2006; Lie and Watten, 1987; Richter et al., 2011a; Simons, 1943).

To date, only a few studies have explored the functional aspects of eye–neck–shoulder interactions. Lie and Watten (1987) showed increased neck/shoulder muscle activity as a function of visual demands during near work, although they did not measure whether participants met the demands of the visual task (i.e. whether they had sufficiently activated their eye muscles). In a more recent laboratory study compliance with a demanding near work task had sufficiently activated their eye muscles. In a more recent laboratory study compliance with a demanding near work task was assessed by measuring eye-lens accommodation with an auto refraactor (Richter et al., 2010). The study showed that accommodative responses during the near work task were associated with trapezius muscle activity. However, the visual demands were high and not comparable to normal every day computer work demands. Therefore, it remains unknown if visual demands occurring during normal every-day computer work are associated with trapezius muscle activity.

In a binocular minus-lens condition, Richter et al. (2011a) showed that trapezius muscle activation started to increase when subjects began to compensate for experimentally induced blur, i.e. subjects who had increased eye-lens accommodation, also exhibited higher levels of muscle activity. One hypothesis arising from this result is that eye-lens accommodation, through ciliary muscle activity, is a mediating mechanism behind increased trapezius muscle activity. One way to study the isolated effect of accommodation is through monocular viewing (i.e. viewing with one eye). Monocular viewing does not require convergence to be actively involved when an object at near is brought into focus. Successful performance under monocular viewing involves only sustained contraction of the ciliary muscles to overcome blur while the convergence is inactive (Franzén et al., 2000). Another hypothesis arising from the study by Richter et al. (2011a) is that incongruence between accommodation and convergence give rise to trapezius muscle activation. Incongruence occurs when there are conflicting demands on accommodation and convergence. It has been shown that incongruence can cause work-related visual fatigue (Birnbaum, 1984; Ukai and Howarth, 2008), and in the clinic, convergence insufficiency is associated with musculoskeletal discomfort (Borsting et al., 2003; Sucher, 1994). Incongruence between accommodation and convergence can be created by making subjects binocularly focus at an object at near through minus lenses. The minus-lenses require increased accommodation, while convergence remains fixed on the object. Increased accommodation leads to increased incongruence between accommodation and convergence responses (Miles et al., 1987).

Several studies have reported that computer users with neck pain have increased neck/shoulder muscle activation under a variety of working conditions (Szeto et al., 2005a,b,c). Increased muscle activity amplitude and reduced rest time in motor units during computer work among subjects with neck pain has also been reported (Hägg and Aström, 1997; Thorn et al., 2007). Whether persons suffering from prolonged neck pain employ different levels of neck/shoulder muscle activity than healthy controls in response to visually demanding near work has not yet been fully explored (Hoyle et al., 2011; Richter et al., 2011a; Treaster et al., 2006; Valentino and Fabozzo, 1993).

The overall purpose of this study was to use a computer based task with realistic visual demands to investigate whether sustained periods of accommodation and convergence affects trapezius muscle activity. The first aim (i) was to investigate whether eye-lens accommodation, through ciliary muscle activity, is a mediating mechanism behind increased trapezius muscle activity. The second aim (ii) was to investigate if incongruence between accommodation and convergence affects trapezius muscle activity. And the third aim (iii) was to investigate whether presence or absence of neck/shoulder discomfort affects trapezius muscle activity during visually demanding near work.

2. Materials and methods

2.1. Participants

Thirty-three participants with neck pain (median age 39, range 20–47, 27 females and 6 males) and 33 healthy age and gender matched controls (median age 37, range 19–47, 27 females and 6 males) were recruited. The inclusion criteria for the neck group were experience of neck/shoulder pain during the last 12 weeks, and 10–68 points on the Neck Disability Index (Vernon and Mior, 1991). The median score on Neck Disability Index was 26 (range 10–50). To exclude participants with eye diseases, the participants were examined by a licensed optometrist. No one was excluded due to eye diseases. The optometrist also assessed visual acuity for distance with a Snellen chart. All participants were recruited through advertisement. Informed consent was obtained from each participant and the study was approved by the Uppsala University Medical Ethical Review Board, Uppsala, Sweden (2006:027).

2.2. Procedure

Participants visited the laboratory on one occasion and undertook visually demanding near work at a computer screen. A standardized vision task was performed four times; each time with different trial-lenses mounted on trial frames. The session started with preparations, where refraction errors were measured with an auto refractor (Power Refractor R03, Plusoptix, Nürnberg, Germany) (Blade and Candy, 2006) and trial-lenses for the experiment were selected. Any spherical refractive errors (±0.25 D) detected were corrected with trial-lenses during the experiment. Thereafter the participant’s dominant eye was determined using a modified version of Dolmans method. Participants were instructed to form a hole using both hands, hold the hands with straight arms in front of the eyes, and focus on a target approximately 3 m away, through the hole. The participant then closed one eye at the time, and when the dominant eye was closed, the participant could not see the target (Cheng et al., 2004; Fink, 1938). Binocular accommodation ability was measured with the RAF ruler (Clement Clark International, Harlow, Essex, UK) (Antona et al., 2009; Rosenfield and Cohen, 1996) with the eyeglass correction needed according to the auto refractor. Next, the participant was set-up with electrodes for electrocardiography (ECG) and electromyography (EMG). ECG was collected through two disposable pre-gelled general-purpose snap electrodes placed laterally on each sixth rib (ELS03, BIOPAC Systems, Inc., Santa Barbara, CA, USA). EMG was collected bilaterally from the descending part of the upper trapezius muscles with two disposable Ag-electrodes (Neuroline 725, Ambu A/S, Ballerup, Denmark) gelled with 0.5% saline-based electrode paste (GE101, BIOPAC Systems, Inc., Santa Barbara, CA, USA). The electrodes were centered 20 mm lateral to the midpoint of the line between vertebra C7 and acromion, with a center-to-center distance of 20 mm. A reference electrode was placed on C7 (Mathiassen et al., 1995). At each recording site the skin was rubbed with fine abrasive paper and cleaned with alcohol. Thereafter, each participant did three normalization trials using submaximal reference contractions (Mathiassen et al., 1995). The trials were 15 s in duration interspaced by 30 s of rest. Reference contraction used was 90° abduction in shoulder joint with straight elbows and relaxed wrist joints. The participant was then seated in an office chair in front of a...
computer screen. Posture was adjusted for comfort, with the head, neck, and back supported, and the hands resting on the lap. Preparations ended with a trial run of the vision task.

The experiment included four blocks. Each block started with 3 min rest when the participant sat relaxed and leaned back with eyes closed. Rest was followed by a 7-min vision task. During each block, different amount of defocus blur was introduced by four different trial-lenses. EMG and ECG were continuously measured during the rests and vision tasks. Pupil size, eye-lens accommodation and convergence were collected with the auto refractor during vision tasks. Due to the auto refractor, participants were instructed to keep the posture and minimize movements. After the four blocks, binocular accommodation ability was measured again to detect any changes due to the experiment. Fig. 1 shows an outline of the set-up in the laboratory.

2.3. The vision task

The vision task consisted of 7 min of sustained foveal focusing on a contrast varying image displayed on a computer screen (Sony F520 CRT monitor and a VSG video board. Cambridge Research System Ltd., Rochester, UK) (Richter and Knez, 2007)). The image consisted of a fixation cross on a black- and white sine wave Gabor grating. A Gabor grating is a zebra-striped pattern, frequently used as visual stimuli (Campbell and Robson, 1968). Distance to screen was 0.65 m (1.5 D) and the center of the grating was placed in the midline of the eyes, with the gaze angle approximately 15° downwards. For maximal stimulation of accommodation, the spa-
tial frequency of the Gabor grating was set to 5 c/deg (Owens,
1980), corresponding to 2.3 mm center-to-center distance between two bright or two dark stripes on the screen.

Before the vision task started, the contrast of the Gabor grating was zero and only the fixation cross was visible (Fig. 2a). To start the vision task, the participant pushed a hand-held, low-force button and the contrast of the grating increased (speed 0.8%/s.) (Fig. 2b,c). When the participant perceived the grating, he/she pushed the button. This was repeated for 7 min. A standard-
ized task instruction emphasized active accommodation: “Look at the fixation cross and the black-and-white pattern. Carefully focus on the fixation cross so that it is maximally sharp and clear at all times” (cf. (Atchison et al., 1994; Richter and Knez, 2007)).

2.4. Trial-lens conditions

Four different trial-lens conditions were used to induce defocus blur during the vision tasks. Trial-lenses were mounted on trial frames (Oculus Inc., Dutenhofen, Germany), and lens order was randomized among participants with a Latin square. Three monocular trial-lens conditions were used to study aim (i), whether eye-lens accommodation, through ciliary muscle activity, is a mediating mechanism behind increased trapezius muscle activity. Previous research have found significant relations between the accommodative response and muscle activity when minus or plus trial-lenses were placed in the line of sight (Richter et al., 2010), therefore the monocular trial-lenses used in this study were: −3.5 D (monocular minus, MM); ±0 D (monocular neutral, MN); and +3.5 (monocular plus, MP), where MN served as a neutral refer-
ence. During the monocular trial-lens conditions, the non-domi-
nant eye was covered. To study aim (ii), if incongruence between accommodation and convergence affects trapezius muscle activity, a binocular trial-lens condition was used (−3.5 D, binocular minus, BM). All four trial-lens conditions were used to analyze aim (iii), whether presence of neck/shoulder discomfort affect trapezius muscle activity during visually demanding near work.

Accommodation stimuli in each of the four trial-lens conditions were fixed and determined by the sum of the spherical power of the trial-lens(es) and the distance to the screen (expressed in D), while accommodation response varied and was assessed with the auto refractor. Accommodation stimuli were 5.0 D in the minus-lens conditions (BM and MM), 1.5 D in the neutral-lens condition (MN) and −2.0 D in the plus-lens condition (MP). To overcome the experimentally induced blur in the minus-lens conditions and obtain a maximally sharp image of the grating, the participant had to sustain ciliary contraction corresponding to a 5 D change of optical power in the eye-lens.

2.5. Data recording during experiment and data processing

During the vision tasks the auto refractor continuously sampled data on pupil size, accommodation and convergence with a frequency of 25 Hz (cf. Richter et al., 2010; Hunt et al., 2003; Wolffsohn et al., 2002). For the auto refractor to detect the eyes and sample data, the eyes had to be aligned to the measurement axis of the auto refractor. To ensure a sufficient number of data...
points from the auto refractor, movements were prevented by supporting the participant’s head and trunk. Data on pupil size were only used to identify inaccurate recordings.

Auto refractor data from the entire 7-min vision task files were imported into MATLAB 7.1 (MathWorks, Inc., Natick, USA). Individual means of accommodation response were computed for each of the 7-min vision task (unit: diopters, D). Accommodation response is the refraction performed by the crystalline eye-lens, i.e. how much the refractive power of the eye-lens has changed due to ciliary muscle activity. In this study, accommodation response is used as an indirect measure of ciliary muscle activity. For accommodation response, only data from the dominant eye were used in analyses. In contrast, data from both eyes are needed to obtain accurate measures of convergence. Therefore this measure was only valid in the binocular trial-lens condition. An individual mean of the convergence of the 7-min vision task was computed and converted into convergence response (unit: diopters, D). More details on converting accommodation and convergence data are presented by Richter et al. (2010).

One limitation with the auto refractor is that it cannot sample data when the pupils are too constricted (pupil diameter <2.8 mm): this was observed in all lens conditions, particularly in the minus-lens conditions when ciliary contraction was high. Thus, the accommodation response might be underestimated in the minus-lens conditions, even though participants had high task compliance. In each lens condition, participants with ≤25% of sampled data from the auto refractor were excluded from the analyses (number of excluded cases in BM = 23, MM = 18, MN = 10 and MP = 10).

Throughout the vision task, the participant indicated with the low-force hand-held button when the Gabor grating became visible and when it no longer could be perceived. Each time the participant pushed the button, the contrast of the Gabor grating was decreased and when it no longer could be perceived. Each time the participant pushed the button, the contrast of the Gabor grating was recorded. Individual mean contrast thresholds were computed and used to verify task compliance.

EMG and ECG were recorded both during rests and during vision tasks. EMG and ECG signals were amplified, band-pass filtered (EMG: 10–500 Hz, ECG 0.05–35 Hz), and sampled at 2000 Hz (EMG100C, BIOPAC Systems, Inc., Santa Barbara, CA, USA). ECG was used to reduce disturbances from heart signals on raw EMG by applying a procedure similar to an approach used to cancel out the maternal ECG in a fetal ECG signal (Widrow et al., 1975). In our approach, the ECG disturbances were assumed to be stable over the heartbeats in each condition. The timing of the R-peaks in the ECG signals was estimated, and the ECG contributions around the R-peaks (±0.2 s) in the EMG signals were averaged from the rest measurements. The estimated contributions were then subtracted from the EMG signals. To identify the timings of the QRS peaks in the ECG, the signal was down-sampled to 1000 Hz and high-pass filtered by a third-order Butterworth filter with a cut-off frequency of 4 Hz. The signal was then divided into 2-s windows and the lowest, maximum value from these periods was identified: the threshold value for identifying R-peaks was set at 0.78 of this maximum value (Forsman et al., 2009).

The EMG recordings were root-mean-square (RMS) converted in 0.1-s windows, quadratically adjusted for noise (the lowest 0.4 s moving RMS value of the recordings during rest), and normalized to submaximal reference contractions. The mean RMS value of the middle 10 s of three 15 s submaximal contractions was used to normalize and express the measurement data in %RVE (reference voluntary electrical activity). The 10th percentile of the normalized RMS-values was chosen as an indicator of the static muscular activity level (Jonsson, 1982; Richter et al., 2011a; Thorn et al., 2007). The 10th percentile of the RMS-value is the value that 10% of the sampled data from the full measurement period are below. It may also be described as “for 90% of the time, the RMS-values were higher than the 10th percentile RMS value”. For the rest period the 10th percentile of the last minute of three was used in the analyses (EMGrest). For the vision tasks, two measures of static muscular activity were used in the analyses: the 10th percentile of the full measurement period (EMGfull 7min); and the 10th percentile of the last third (140 s) of the full measurement period (EMGlast 140s). The reason for this was the recent finding that EMG may increase over time during demanding near work (Richter et al., 2012).

2.6. Statistical analyses

All variables were tested for normality with the Kolmogorov–Smirnov test, and statistical tests were chosen based on data distribution. The Mann Whitney U-test was used to analyze differences on corrected visual acuity between the two groups. One repeated measure ANOVA analyzed differences in accommodation ability before and after the four viewing tasks and differences in accommodation ability between groups. Differences in accommodation response between groups and among trial-lens conditions was analyzed with one repeated measure ANOVA, thereafter Bonferroni adjusted pairwise comparisons were used to analyze differences between the trial-lens conditions.

Wilcoxon signed-rank test was used to determine differences between right and left trapezius muscle activity (EMGrest and EMGfull 7min) and tested separately within lens condition and within group. For these analyses, the neck group was divided into subgroups depending on whether the pain was right-sided, left-sided or bilateral. Since there were no participants with left-sided pain, the subgroups were right-sided pain (n = 8), and bilateral pain (n = 25). Differences were tested for the entire neck group and for the two subgroups.

To verify that the participants had the same level of trapezius muscle activity during rest across the experiment (EMGrest), differences were tested with the Friedman test. Four separate Wilcoxon signed-rank tests (one for each trial-lens condition) were used to verify that the vision task did affect muscle activity (EMGfull 7min), compared to rest levels (EMGrest). The Friedman test was used to analyze differences in muscle activity among trial-lens conditions during vision tasks (EMGfull 7min), without regard to individual compliance with the task.

To investigate aim (i) whether trapezius muscle activity was affected by eye-lens accommodation, a stepwise regression model were used for each monocular trial-lens condition (MM, MN and MP). As the EMG-data were non-normally distributed, all EMG variables were transformed with the natural logarithm. The regression model was run with both logEMGfull 7min and logEMGlast 140s as the dependent variable. The independent variables were accommodation ability, accommodation response, group (control/neck) and logEMGrest. In the first step of the regression model, the contributions of all independent variables were calculated, and the variable explaining most of the variance was included in the model (if p < 0.05). The remaining variables were checked, and all variables with p > 0.1 were removed. The model was re-estimated with the remaining variables, and the process continued until no more variables made a significant contribution. The stepwise regression model was used to minimize suppression effects (Field, 2009).

The same stepwise regression model was used on data from the binocular trial-lens condition (BM) to evaluate aim (ii) whether trapezius muscle activity was affected by incongruence between accommodation and convergence. In this model, convergence response was also included as an independent variable.

The regression models (BM, MM, MN, MP) were also used to investigate aim (iii) whether trapezius muscle activity was affected by presence or absence of neck/shoulder discomfort.
Statistical analyses were performed with PASW 20.0 for Windows (SPSS Inc., Chicago, IL, USA), and the significance level was \( \alpha = 0.05 \).

3. Results

3.1. Visual acuity and accommodation ability

All participants had normal corrected visual acuity (range 1.0–1.2). The Mann Whitney U-test revealed no difference in visual acuity between the control group and the neck group (\( p > 0.30 \)). Descriptive results for accommodation ability are presented in Table 1. Forty-three participants had accommodation ability above 5 D and were theoretically able to fully comply with the vision tasks in BM and MM. The repeated measure ANOVA revealed a significant decrease in accommodation ability after the four vision tasks (\( F(1, 64) = 14.64, \text{eta}^2 = 0.19, p < 0.001 \)). There were no differences in accommodation ability between groups (control/neck) (\( p = 0.434 \)).

3.2. Accommodation- and convergence response, and contrast thresholds

Mean valid sampled data from the auto refractor for all 66 participants were 68% (sd 21, \( n = 43 \)) in BM, 69% (sd 22, \( n = 48 \)) in MM, 72% (sd 22, \( n = 56 \)) in MN, and 77% (sd 18, \( n = 56 \)) in MP. Mean accommodation responses are presented in Table 1. The repeated measure ANOVA with one within factor (trial-lens condition: BM, MM, MN, MP) and one between factor (group: control, neck) showed a significant main effect of trial-lens condition on accommodation response (\( F(3, 108) = 38.221, \text{eta}^2 = 0.515, p < 0.001 \)), but no difference between the groups (control/neck). Pairwise comparisons revealed significant differences in accommodation response, with higher responses in BM and MM compared to MN and MP, and higher response in MN compared to MP. There was no significant difference in accommodation response between the two minus-lenses conditions (BM and MM). The mean convergence response in trial-lens condition BM was 1.06 D (sd 0.63) (\( n = 43 \)). Median contrast thresholds were 9.2 (IQR 16.9) in BM, 9.5 (IQR 18.1) in MM, 3.2 (IQR 1.7) in MN, and 27.9 (IQR 18.3) in MP (\( n = 65 \) in all lens conditions).

3.3. Trapezius muscle activity

EMG with sufficient quality was recorded from all participants except three, who were excluded due to poor signal quality. All ECG recordings had sufficient quality. Fig. 3 illustrates a typical EMG and ECG recording from a vision task, from band passed filtered and sampled raw data to RMS converted data. The Wilcoxon signed-rank test showed no significant difference between right and left trapezius muscle activity within trial-lens conditions and group (\( p > 0.2 \)). Thus, in subsequent analyses an average of right and left trapezius muscle activity was used. Mean values of the 10th percentile EMG RMS value for the rest (\( \text{EMG}_{\text{rest}} \)) and the vision tasks (\( \text{EMG}_{\text{full 7min}} \)) for the four trial-lens conditions are presented in Table 2. No difference in \( \text{EMG}_{\text{rest}} \) across the experiment was found (\( p = 0.30 \)). For all trial-lenses, \( \text{EMG}_{\text{full 7min}} \) was higher than \( \text{EMG}_{\text{rest}} \) (\( p < 0.01 \)). During the vision task, no significant difference in \( \text{EMG}_{\text{full 7min}} \) was found among the trial-lenses (\( p = 0.38 \)).

3.4. The stepwise regression models

Significant results from the regression models are presented in Table 3. For the monocular trial-lens conditions the stepwise regression models analyzed aim (i) whether eye-lens accommodation was a mediating mechanism behind increased trapezius muscle activity. There were no significant effects of accommodation response either on \( \text{logEMG}_{\text{full 7min}} \) or on \( \text{logEMG}_{\text{last 140s}} \) in any of the monocular trial-lens conditions (\( p > 0.16 \)). This means that eye-lens accommodation was not a mediating mechanism behind trapezius muscle activity. One variable came out significant in all monocular models: \( \text{EMG}_{\text{rest}} \). In addition, a small but significant effect of accommodation ability was present in the plus-lens condition (MP), but only when the last third of the vision task EMG was analyzed (\( \text{logEMG}_{\text{last 140s}} \)). The effect of accommodation ability in trial-lens condition MM and MN were non-significant (\( p > 0.06 \)). The residuals of the models were normally distributed, and no autocorrelations were detected.

For the binocular trial-lens condition, the stepwise regression was used to evaluate aim (ii) whether trapezius muscle activity was affected by incongruence between accommodation and convergence. The dependent variables were \( \text{logEMG}_{\text{full 7min}} \), \( \text{logEMG}_{\text{rest}} \), and \( \text{logEMG}_{\text{last 140s}} \), and the independent variables were accommodation ability, accommodation response, convergence response, group (control/neck), and \( \text{logEMG}_{\text{rest}} \). In both cases accommodation response had a significant effect on trapezius muscle activity: it accounted for 10% of the variance on \( \text{logEMG}_{\text{full 7min}} \) and for 13% of the variance on \( \text{logEMG}_{\text{last 140s}} \) (Table 3). Neither accommodation ability nor convergence response had significant effects (\( p > 0.22 \)). The residuals of the models were normally distributed, and no autocorrelations were detected. Fig. 4 shows the partial correlation between accommodation response and trapezius muscle activity for the four trial-lens conditions, when the effect of muscle activity during rest are controlled for.

The stepwise regressions were also used to investigate aim (iii) whether presence or absence of neck/shoulder discomfort affects trapezius muscle activity. No significant effects of group (control/neck group) were found in any of the models (\( p > 0.13 \)).

4. Discussion

Muscle activity levels were higher during vision tasks than during rest in all four trial-lens conditions, indicating that the vision task did increase muscle activity levels. The difference in

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Trial-lens</th>
<th>Total</th>
<th>( N )</th>
<th>Control group</th>
<th>( N )</th>
<th>Neck group</th>
<th>( N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acc. ability – before VT (D)</td>
<td>–</td>
<td>6.62 (3.10)</td>
<td>66</td>
<td>6.91 (3.18)</td>
<td>33</td>
<td>6.34 (3.03)</td>
<td>33</td>
</tr>
<tr>
<td>Acc. ability – after VT (D)</td>
<td>–</td>
<td>6.01 (3.16)</td>
<td>66</td>
<td>6.32 (3.17)</td>
<td>33</td>
<td>5.70 (3.16)</td>
<td>33</td>
</tr>
<tr>
<td>Acc. response (D)</td>
<td>BM</td>
<td>3.05 (1.99)</td>
<td>43</td>
<td>2.75 (1.90)</td>
<td>23</td>
<td>3.39 (2.09)</td>
<td>20</td>
</tr>
<tr>
<td>Acc. response (D)</td>
<td>MM</td>
<td>3.40 (1.82)</td>
<td>48</td>
<td>3.15 (1.64)</td>
<td>25</td>
<td>3.68 (2.00)</td>
<td>23</td>
</tr>
<tr>
<td>Acc. response (D)</td>
<td>MN</td>
<td>1.50 (0.70)</td>
<td>56</td>
<td>1.49 (0.68)</td>
<td>31</td>
<td>1.51 (0.74)</td>
<td>25</td>
</tr>
<tr>
<td>Acc. response (D)</td>
<td>MP</td>
<td>0.97 (0.91)</td>
<td>56</td>
<td>0.98 (0.84)</td>
<td>29</td>
<td>0.97 (0.99)</td>
<td>27</td>
</tr>
</tbody>
</table>

Acc. = accommodation, VT = vision task, D = diopters, BM = binocular minus, MM = monocular minus, MN = monocular neutral, MP = monocular plus, \( N \) = number of valid cases.
accommodation ability before and after the vision tasks indicates that the vision task in fact was demanding for the visual system. Hypothesis (i) that eye-lens accommodation, through ciliary muscle activity, was a mediating mechanism behind increased trapezius muscle activation was not supported. Eye-lens accommodation did not have a significant effect on trapezius muscle activity in any of the three monocular trial-lens conditions. In the monocular-minus condition (MM), the accommodation responses were comparable to those in the binocular-minus condition (BM), but it was only in BM that a significant relationship between eye-lens accommodation and trapezius muscle activity was evident. This may be interpreted as if the source of increased trapezius muscle activity was due to eye-lens accommodation per se, the relationship would be expected to appear also in MM. An important difference between BM and MM was that BM involved convergence and that the demands on accommodation and convergence were incongruent. The significant relation found in the binocular condition, and the non-significant results in the monocular conditions was consistent for both measures of static muscular activity, i.e. the 10th percentiles of the full and the last third of the

**Table 2**

<table>
<thead>
<tr>
<th>Lens condition</th>
<th>Total</th>
<th></th>
<th>Control group</th>
<th></th>
<th>Neck group</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rest</td>
<td>Vision task</td>
<td></td>
<td>Rest</td>
<td>Vision task</td>
<td></td>
</tr>
<tr>
<td>BM</td>
<td>0.52 (0.34)</td>
<td>0.71 (0.61)</td>
<td>0.49 (0.31)</td>
<td>0.66 (0.67)</td>
<td>0.56 (0.37)</td>
<td>0.76 (0.55)</td>
</tr>
<tr>
<td>MM</td>
<td>0.56 (0.45)</td>
<td>0.80 (1.05)</td>
<td>0.45 (0.28)</td>
<td>0.70 (0.58)</td>
<td>0.66 (0.55)</td>
<td>0.90 (1.37)</td>
</tr>
<tr>
<td>MN</td>
<td>0.52 (0.41)</td>
<td>0.71 (0.86)</td>
<td>0.41 (0.19)</td>
<td>0.67 (0.79)</td>
<td>0.63 (0.51)</td>
<td>0.74 (0.93)</td>
</tr>
<tr>
<td>MP</td>
<td>0.51 (0.45)</td>
<td>0.78 (0.74)</td>
<td>0.37 (0.18)</td>
<td>0.59 (0.95)</td>
<td>0.66 (0.58)</td>
<td>0.66 (0.44)</td>
</tr>
</tbody>
</table>

BM = binocular minus, MM = monocular minus, MN = monocular neutral, MP = monocular plus.

**Table 3**

Results from the regression models.

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Trial-lens condition</th>
<th>Independent variable</th>
<th>Coefficient (B)</th>
<th>(R^2)-change</th>
<th>(p)-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>logEMGfull 7min</td>
<td>BM</td>
<td>logEMGrest</td>
<td>0.609</td>
<td>0.327</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Acc. response</td>
<td>0.199</td>
<td>0.101</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MM</td>
<td>logEMGrest</td>
<td>0.583</td>
<td>0.348</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>MN</td>
<td>logEMGrest</td>
<td>0.567</td>
<td>0.268</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>MP</td>
<td>logEMGrest</td>
<td>0.478</td>
<td>0.187</td>
<td>0.001</td>
</tr>
<tr>
<td>logEMGlast 140s</td>
<td>BM</td>
<td>logEMGrest</td>
<td>0.587</td>
<td>0.206</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>Acc. response</td>
<td>0.152</td>
<td>0.134</td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MM</td>
<td>logEMGrest</td>
<td>0.712</td>
<td>0.342</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>MN</td>
<td>logEMGrest</td>
<td>0.531</td>
<td>0.148</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>MP</td>
<td>logEMGrest</td>
<td>0.538</td>
<td>0.140</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>Acc. ability</td>
<td>0.078</td>
<td>0.066</td>
<td>0.043</td>
<td></td>
</tr>
</tbody>
</table>

log = logarithmised value, EMGfull 7min = 10th percentile EMG of the 7-min vision task, EMGlast 140s = 10th percentile EMG of the last 140 s of the 7-min vision task, EMGrest = 10th percentile EMG from the rest period, BM = binocular minus, MM = monocular minus, MN = monocular neutral, MP = monocular plus, Acc. = accommodation.

* Only variables with \(p \leq 0.05\) are presented in the table.

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measurement period. These results support the second hypothesis that incongruence between accommodation and convergence may increase trapezius muscle activity. This was also observed by Richter et al. (2010) who found linear relationships in two incongruent trial-lens conditions (binocular-minus and binocular-plus) between accommodation response and trapezius muscle activity. In the regression models for the binocular lens-condition, both accommodation and convergence response were included, but only accommodation response had a significant effect on trapezius muscle activity. This result was expected since the demand on the convergence system was low (1.5 D), compared to the demand on the accommodation system (5.0 D). For the plus-lens condition, accommodation ability had a very small but significant effect on trapezius muscle activity, but only on the EMG RMS from the last third of the vision task. There is no obvious explanation or interpretation of the result, and taken together, the scientific relevance of this finding is unclear.

It would have been an advantage to calculate the ratio between accommodation and convergence to obtain an estimate of the incongruence on individual level. But since the convergence measurements from the auto refractor were unstable, and several of the individual values were close to zero, it was not possible to use convergence as a nominator to calculate the ratio. However, with a stable convergence, the true incongruence should be expected to correlate well with the accommodation response. The finding that the muscle activity partly depends on the accommodation response may therefore be interpreted as an association between muscle activity and incongruence.

Presence or absence of neck/shoulder discomfort did not affect trapezius muscle activity. The independent variable ‘group’ (control/neck) did not contribute significantly in any of the regression models. This indicates that the mechanism involved in neck stabilization during high visual demands may not be affected by the individual factor of prolonged neck pain.

The 10th percentile of the EMG RMS-values was chosen as a parameter of muscular load because it refers to the static muscular activity level and is inversely related to the relative rest time (Thorn et al., 2007), and is therefore related to the Cinderella hypothesis. The Cinderella hypothesis (Hagg, 1991, 2000) is based on prescribed motor unit recruitment and de-recruitment size-principle order and is supported by findings from cell morphology studies in myalgic muscles (Kadi et al., 1998a,b). It proposes that low-threshold motor units are recruited at low levels of contraction, and that they continue to be activated until the muscle is completely relaxed. The prolonged activation of these motor units may result in a degenerative process causing pain. Results from this study imply that incongruence between accommodation and convergence in combination with other factors, such as mental and postural strain, may induce a muscular activity above the threshold of the low-threshold motor units. In accordance with the Cinderella hypothesis, this may overload specific muscle fibers, and cause pain through structural and chemical changes.

In this study the participants were instructed to maintain a static posture. This was necessary in order to measure eye-lens accommodation and convergence with the auto refractor. Even though the office chair supported the head and back, the fixed posture could hypothetically have affected muscle activity. However, as the posture instructions were identical for all trial-lens conditions, it is unlikely that the fixed posture affected muscle activity to a higher degree in the binocular trial-lens condition, and only for participants with high accommodative responses. If the fixed posture affected muscle activity, it ought to appear in all trial-lens conditions.

Even though the posture instructions aimed to increase the percentage of sampled data from the auto refractor, there were substantial losses of data in the auto refractor measurements. This was, for example, due to reflections in the trial-lenses and small pupil sizes (cf. Richter et al., 2010). Thus, much data from the auto refractor were considered unreliable and excluded from the analyses. Consequently, only 41 of the 66 participants were included in the regression model analyzing the binocular trial-lens condition. There were also data losses in the EMG measurements due to technically unreliable signals, and the 10th percentiles of the EMG RMS-values were low and rather close to the noise level. These factors limited the power of the statistical analyses.

The overall purpose of this study was to use a computer based task with realistic visual demands to investigate whether sustained periods of accommodation and convergence affects trapezius muscle activity. The accommodation stimuli in the minus-lens conditions were 5 D and the mean accommodation response were 3 D and 3.4 D. In the previous study by Richter et al. (2011a) the average accommodation stimuli in the minus-lens condition was approximately 8 D. Eight diopeters is equal to 0.13 m viewing distance, 5 D correspond to a viewing distance of 0.2 m, and 3 D correspond to 0.33 m. When doing near work, e.g. computer work, the computer screen is usually at least 0.4 m away. A recommended

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distance to screen is 0.50–0.85 m (Rempel et al., 2007), and in another study, the mean self-selected optimal distance to screen was 0.63 m (±0.13) (Jaschinski, 2002). For most people doing near work at a computer, the visual demands to which they are normally exposed to, are lower than the demands in the minus-lens conditions in this study. On the other hand, there is an increasing use of tablets and smart phones both during work and leisure. The viewing distance for tablets and smart phones are shorter than for a computer screen thus increasing the demands on the visual system. The demands on accommodation when doing near work at a smart phone are comparable to accommodation responses found in this study. In addition, the experimental demand only lasted for 7 min per trial-lens condition, a total of 28 min, and this should be compared with a working time of between 4 and 8 h of near work for employees with predominantly computer-based work tasks. Even though the experimental time was short, the decrease in accommodation ability after the experiment shows that the visual tasks were visually demanding. The decrease in accommodation ability was expected, since sustained contraction of the ciliary muscle can result in transient myopia (Rosenfield and Gilmartin, 1998).

The relatively high visual demands, the short experimental time, and the instruction for participants to sit in a fixed position differed from typical working conditions. When these factors are considered, the results should be translated and interpreted with caution in real working life situations. Despite these limitations, the findings suggested that incongruence between accommodation and convergence in combination with other factors, such as stress and postural strain may contribute to the development of near-work related neck/shoulder discomfort. To further progress the field of visual ergonomics, the results from this study and the research techniques developed in the laboratory should be applied to relevant occupational environments.

5. Conclusion

A significant relationship between accommodation response and trapezius muscle activity was observed. As the relationship was present only in the binocular trial-lens condition, incongruence between accommodation and convergence appeared to be involved, rather than eye-lens accommodation alone. The relatively low demands on accommodation and convergence in the present study imply that visually demanding near work may contribute to increased muscle activity, and over time to the development of near work related neck/shoulder discomfort; thus, visual ergonomics is an important factor when evaluating the ergonomic environment at a computer workstation. Further scientific work is necessary for understanding the eye–neck/scapular area synergies developing during visually demanding near work.

Conflict of interest

None declare

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