The impact of visually demanding near work on neck/shoulder discomfort and trapezius muscle activity

Laboratory studies

CAMILLA ZETTERBERG
Abstract

Introduction: Musculoskeletal discomfort in the neck and shoulders is common among workers performing visually demanding near work, e.g., on a computer screen, and sustained low-level muscle activity during such work can lead to work-related pain. The relationships between visual demands and muscle activity and discomfort in the neck/shoulder region are at present unclear. Aim: The aims of this thesis were to determine whether neck/shoulder discomfort and trapezius muscle activity increases during visually demanding experimental near work, and to investigate whether eye-lens accommodation is a mediating mechanism behind increased trapezius muscle activity. Methods: The four papers included are based on two experiments with different visually demanding near work tasks (duration 5 and 7 min). Trial lenses of different diopters were used to manipulate the visual demands (i.e., induce more or less accommodation) and thereby create different viewing conditions. Monocular viewing, which does not require active convergence, was used to examine the isolated effect of accommodation. Eye-lens accommodation and trapezius muscle activity were measured continuously during the visual tasks, and in one experiment the participants rated their eye and neck/shoulder discomfort at baseline and after each visual task. Results: Neck/shoulder discomfort and trapezius muscle activity increased during the visually demanding near work and participants experiencing a greater increase in eye discomfort (compared with baseline) also developed more neck/shoulder discomfort with time. There were no significant differences in muscle activity among the viewing conditions, and no effect of isolated accommodation response within the monocular viewing conditions. Conclusion: These findings indicate that accommodation per se is unlikely to mediate trapezius muscle activity. Instead, the increase in trapezius muscle activity observed here may be due to a combination of high visual attention and enhanced requirement for eye-neck (head) stabilisation. Since these results suggest that neck/shoulder discomfort may aggravate with time when the visual demands are high, it is important to provide good visual conditions in connection with visually demanding occupations.

Keywords: Accommodation, Asthenopia, Computer work, Eye-neck (head) stabilization, Muscle activity, Neck pain, Visual Attention, Visual demand, Visual ergonomics

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To me myself and Vilma
List of Papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.

I  Zetterberg, C., Forsman, M., and Richter, H.O. Neck/shoulder discomfort due to visually demanding experimental near work is influenced by previous neck pain, task duration, astigmatism, eye discomfort and accommodation. *Manuscript*.


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Abbreviations

ANOVA Analysis of variance
CI Confidence interval
D Diopters
ECG Electrocardiography
EMG Electromyography
GEE General estimating equation
HRV Heart rate variability
NDI Neck disability index
RVE Reference voluntary electrical activity
VC Viewing condition
  BM Viewing condition with -3.5 diopters binocular trial lenses
  MM Viewing condition with -3.5 diopters monocular trial lenses
  MN Viewing condition with 0 diopters monocular trial lenses
  MP Viewing condition with +3.5 diopters monocular trial lenses
Introduction

Traditionally, ergonomic improvement at the workplace has focused on reducing the physical exposures on the musculoskeletal system (e.g., heavy lifting, manual handling, and awkward postures). As a consequence of the development of information and communication technologies and growth of the service sector many tasks are now performed on the computer screen, rather than on the factory floor leading to new forms of physical exposure on the musculoskeletal system. Sedentary computer-based tasks impose low, but sustained physical demands on the musculoskeletal system (e.g., prolonged low-level muscle activity), resulting in a high prevalence of discomfort in the neck/shoulder area. The underlying mechanisms are not fully understood, but it is assumed that sustained muscle activity, even of very low amplitude, can give rise to pain.

Visual ergonomics, a broad multidisciplinary area, including e.g., lighting, visually demanding near work, visual function and comfort (Anshel 2005), has been defined by the International Ergonomics Association as follows (IEA 2012; Long, Toomingas, Forsman, Glimne et al. 2014):

Visual ergonomics is the multidisciplinary science concerned with understanding human visual processes and the interactions between humans and other elements of a system. Visual ergonomics applies theories, knowledge and methods to the design and assessment of systems, optimizing human well-being and overall system performance. Relevant topics include, among others: the visual environment, such as lighting; visually demanding work and other tasks; visual function and performance; visual comfort and safety; optical corrections and other assistive tools.

The current thesis focuses on neck/shoulder discomfort and trapezius muscle activity in connection with visually demanding experimental near work.

Near work

As early as the 18th century, the risk for visual problems during near work was recognized. Thus, in 1713, Ramazzini reported that workers who continuously focused their eyes on the “black letters” were troubled by “weakness of vision” (Ramazzini 2001). In Sweden 2013, 78% of Swedish em-
employees performed some computer work, with 20% working almost con-
tantly on a computer (Arbetsmiljöverket 2014). Although predominantly
computer-based, near work today also includes, for example, microscopy,
inspection and/or manufacturing of small details (e.g., circuit cards), surgery
and dentistry.

**The near triad**

Seeing any near object clear requires coordination between accommodation,
vergence and depth of focus by the eyes (the near triad). Accommodation,
the dynamic alteration of the optical power of the crystalline eye lens ena-
bles focus to be changed from distant to nearby objects. In primates, this
process is mediated by contraction of the ciliary muscles (Kaufman, Alm
and Adler 2003). Vergence involves simultaneous movement of both eyes to
maintain single vision during normal binocular viewing. To focus on a near-
by or distant target, the eyes rotate towards (convergence), or away from
each other (divergence), respectively, under control of the extraocular mus-
cles (Kaufman et al. 2003). The iris regulates the amount of light entering
the eye, and hits the retina, by adjusting the size of the pupil, where a small
size increases the depth of focus in a manner similar to the pinhole effect
with a camera.

During normal viewing, this near triad is closely coordinated. To bring a
nearby object into focus, accommodation enhances the refractive power of
the lens, convergence maintains single vision, and constriction of the pupils
enlarges the depth of focus. These demands on the visual system rise as the
viewing distance declines (Miles, Judge and Optican 1987; Kaufman et al.
2003).

**Visual defects**

Normally, parallel rays of light reflected from a distant object are focused
onto the retina to achieve a sharp and clear image, but with a refractive error
the rays cannot be focused in this manner and the image is blurred. The most
common refractive errors are myopia, hyperopia, astigmatism and presbyo-
pia. With the myopic, or near-sighted, eye, parallel light rays originating
from the distance are focused in front of the retina and the image is blurred,
whereas near vision is good. Myopic refractive error can be corrected with
diverging (minus) lenses. With a hyperopic, or far-sighted, eye, distant paral-
lel light rays are focused behind the retina and the image is blurred. By in-
creasing its focal power (accommodation), the eye can compensate to a cer-
tain extent for the blur and hyperopic refractive errors can be corrected with
converging (plus) lenses. The curve of the cornea and/or the lens of the as-
tigmatic eye is irregular so that light rays are refracted differently in the ver-
tical and horizontal direction, errors that can be corrected with cylindrical
lenses (Anshel 2005).
In the case of presbyopia, an age-related visual impairment, the crystalline eye lens becomes less elastic, the ability to accommodate decreases, and the ciliary muscles must contract more and more to keep a near object in focus. The first signs of presbyopia, such as blurred near vision, a longer near working distance and a need for brighter light when reading, usually appear between the ages of 40 and 50. This condition can be corrected for with converging (plus) lenses for near vision or with multifocal lenses (AOA 2011a; Richdale, Sinnott, Bullimore, Wassenaar et al. 2013).

Among the binocular vision disorders, convergence insufficiency involves impaired ability of the eyes to converge and maintain binocular focus on a near object. Typical symptoms are double and/or blurred vision and eye-strain and this condition can be treated with convergence exercises and/or prismatic lenses (Lavrich 2010). In the case of heterophoria, the eyes are not properly aligned, resulting in double vision. In most cases this can be compensated for by enhanced vergence, which can, however, cause, e.g., eye-strain and fatigue and headache. If the deviation cannot be compensated for in this manner, the disorder is referred to as heterotropia or strabismus and can be corrected with prismatic lenses (AOA 2011b).

**Eye discomfort during near work**

The most frequent health problems related to working on a computer screen involve the eyes (Blehm, Vishnu, Khattak, Mitra et al. 2005; Rosenfield 2011), and the symptoms are commonly referred to as Computer Vision Syndrome: CVS (defined as a combination of eye and visual problems associated with computer use (http://www.aoa.org)) (Rosenfield 2011; Gowrisankaran and Sheedy 2015). The prevalence of such eye discomfort ranges from 25% to 93% (Knave, Wibom, Voss, Hedström et al. 1985; Dain, McCarthy and Chan-Ling 1988; Mocci, Serra and Corrias 2001; Bhandari, Choudhary and Doshi 2008; Portello, Rosenfield, Bababekova, Estrada et al. 2012; Gowrisankaran et al. 2015), with longer duration of computer work (e.g., more than 4 hours daily) being associated with higher prevalence (Rossignol, Morse, Summers and Pagnotto 1987; Portello et al. 2012).

The two major causes of eye-related problems associated with near work discussed in the scientific literature are demands made on visual function and dryness. Eyestrain, ache in or around the eyes, tired eyes, sore eyes, and blurred or double vision are probably related to elevated demands on convergence or accommodation in combination with accommodative or binocular vision disorders, whereas dry eyes, burning, irritation, tearing and redness are related to dryness (Blehm et al. 2005; Rosenfield 2011; Portello et al. 2012; Gowrisankaran et al. 2015).
The mechanism underlying symptoms due to uncorrected refractive errors is poorly understood, but may involve increased convergence or accommodation required to compensate for uncorrected hyperopia or astigmatism or overcorrected myopia (Gowrisankaran et al. 2015). In experiments both uncorrected and induced astigmatism leads to eye-related symptoms (Wiggins and Daum 1991; Wiggins, Daum and Snyder 1992; Rosenfield, Hue, Huang and Bababekova 2012) and workers with temporarily attenuated accommodation or an accommodative lag, report visual symptoms more frequently (Gobba, Broglia, Sarti, Luberto et al. 1988; Chase, Tosha, Borsting and Ridder 2009).

The elevated accommodative and convergent demands placed by near work induce more self-reported eyestrain, especially when the viewing distance is shorter than preferred (Jaschinski-Kruza 1991; Jaschinski, Heuer and Kylian 1998). In this context, the visual demands made by laptops, tablets and smart phones differ, being greater with small hand-held devices (Bababekova, Rosenfield, Hue and Huang 2011; Rosenfield 2011; Gowrisankaran et al. 2015).

In addition, a number of other environmental factors including design of the work station, lighting, glare, and the quality of the computer screen might exert an impact on eye-related symptoms (Gowrisankaran et al. 2015). Moreover, there are some tentative indications of a relationship between such symptoms and cognitive demands and fatigue and/or psychological factors (Mocci et al. 2001; Woods 2005; Gowrisankaran, Nahar, Hayes and Sheedy 2012; Ostrovsky, Ribak, Pereg and Gaton 2012). Different factors in combination, e.g., an uncorrected refractive error, glare and a short viewing distance, might cause even more eye problems (Blehm et al. 2005; Rosenfield 2011).

In the literature in this area a number of words are used to describe symptoms related to the eyes (Sheedy, Hayes and Engle 2003; García-Muñoz, Carbonell-Bonet and Cacho-Martínez 2014). Here, the term eye discomfort is used synonymously with asthenopia or eye-related symptom.

**Neck/shoulder discomfort during near work**

The term non-specific neck pain is applied to pain in the neck with no known specific or systematic cause (Borghouts, Koes and Bouter 1998; Guzman, Hurwitz, Carroll, Haldeman et al. 2008). The terms utilised to describe musculoskeletal symptoms vary (Johansson, Windhorst, Djupsjöbacka and Passatore 2003), and here neck/shoulder discomfort is used synonymously with non-specific pain in the neck/shoulder area.
Neck/shoulder discomfort is a serious problem among professional users of modern information technology (Wærsted, Hanvold and Veiersted 2010; Madeleine, Vangsgaard, Hviid Andersen, Ge et al. 2013), with a twelve month prevalence among those who use computers intensively of 58%, twice as high as among a control group performing manual work (Woods 2005). Among office workers using a computer for more than one hour per day, the twelve month and one-week prevalence were 55% and 21% respectively (Klussmann, Gebhardt, Liebers and Rieger 2008). In three more recent studies, the prevalence of neck/shoulder complaints among office workers performing more than two hours of computer work daily ranged between 37 to 58% (Ranasinghe, Perera, Lamabadusuriya, Kulatunga et al. 2011; Oha, Animagi, Paasuke, Coggon et al. 2014; Collins and O'Sullivan 2015). Among adolescents, 16-20% reported frequent neck/shoulder discomfort, with screen-based activities (more than 2-3h/day) slightly increasing the risk (Myrtveit, Sivertsen, Skogen, Frostholm et al. 2014; Silva, Pitangui, Xavier, Correia-Junior et al. 2015).

**Aetiology of neck/shoulder discomfort**

Neck/shoulder discomfort in office workers is assumed to be caused by a variety of factors, both physical and psychosocial (Johansson et al. 2003; Visser and van Dieën 2006), e.g., bending the neck forward, sitting for prolonged periods, repetitive work, static muscle activity, mental fatigue, high demands and little control (Cagnie, Danneels, Van Tiggelen, De Loose et al. 2007; Côté, van der Velde, Cassidy, Carroll et al. 2008; Mohan, Justine, Jagannathan, Aminudin et al. 2015). However, the underlying pathophysiological mechanisms are poorly understood (Johansson et al. 2003; Visser et al. 2006). One hypothesis, the so-called Brussels model, is that interaction between multiple factors is involved: static and/or repetitive work influences microcirculation in the muscle, which in turn disturbs metabolism, possibly causing both structural changes and alterations in intramuscular chemistry, that might activate pain receptors and change muscle afferentation (feedback circuits), thereby increasing muscle activity. The Cinderella hypothesis (which is part of the Brussels model) is based on the ordered recruitment of motor units (Henneman, Somjen and Carpenter 1965): motor units with a low-threshold (Cinderella muscle fibres) are recruited first during a muscle contraction, remain active throughout the contraction, and relax last. This could lead to overload and progressive fatigue, which could in turn give rise to the same chemical and structural changes described above (Hägg 1991; Forsman, Birch, Zhang and Kadefors 2001; Johansson et al. 2003). Such a chain of interactions can occur even during prolonged low-intensity static and/or repetitive work, e.g., with a computer (cf. Collins et al. 2015).

According to these hypotheses, not only sustained muscle activity, but also too little muscular rest can lead to pain. A prospective case-control study of
workers performing light manual work revealed that those with less muscle rest more often experienced pain in the trapezius, even though the level of static muscle activity was the same (Veiersted, Westgaard and Andersen 1993). In an investigation involving recording of trapezius muscle activity for 24 hours, neck/shoulder pain correlated positively to muscle activity, but only among workers with longer sustained periods of muscle activity without rest (mostly retail and healthcare workers), and not those with more periods of rest (mostly computer workers and secretaries) (Mork and Westgaard 2006). An experimental investigation revealed an altered muscle recruitment pattern for subjects experiencing more severe neck discomfort, compared with both low discomfort and control groups, with elevated muscle activity especially in the upper trapezius during a 1-h typing task (Szeto, Straker and O'Sullivan 2005). Moreover, among women carrying out standardized computer work in a laboratory setting, experience of pain was associated with more muscle activity and less relative rest time, but only when the work involved psychological stress (Thorn, Søgaard, Kallenberg, Sandsjö et al. 2007). Whether individuals suffering from prolonged neck pain exhibit neck/shoulder muscle activity in response to visually demanding near work that differs from that of healthy individuals has not yet been fully explored (Lie and Watten 1987; Hoyle, Marras, Sheedy and Hart 2011).

**Associations between eye discomfort or visual demands and neck/shoulder discomfort**

Eye and neck/shoulder discomfort associated with near work, are often examined separately, which makes it difficult to determine whether they are independent symptoms or related physiologically (Blehm et al. 2005; Woods 2005; Robertson, Ciriello and Garabet 2013). Some evidence indicates an association. For example, among call-centre workers these two forms of discomfort occurred together in 21% of the cases, and were associated (Wiholm, Richter, Mathiassen and Toomingas 2007), and among office workers eye discomfort explained 53% of the variance in neck/shoulder discomfort (Helland, Horgen, Kvikstad, Garthus et al. 2008). In connection with a an intervention involving postmen, those experiencing eye discomfort at the outstart reported more shoulder discomfort and with the improved lighting both neck and shoulder discomfort were lower among the postmen without eye strain (Hemphälä and Eklund 2011). Recently, eye and musculoskeletal discomfort among office workers were shown to be reduced by ergonomic training in combination with adjustment of their workstations (Robertson et al. 2013).

It is assumed that the body prioritizes good vision over a good posture: “The eyes lead the body” (Anshel 2005). For example, when reading a small font on a computer screen, one might need to lean forward, which could increase the mechanical and muscular load on the neck and in the long run result in
discomfort (Szeto et al. 2005; Cagnie et al. 2007). In this manner neck discomfort may arise from inappropriate viewing conditions during near work, but it remains unclear whether visual demands per se can trigger neck discomfort (Richter, Bänziger and Forsman 2011).

When two experimental groups performed similar keyboard work, those exposed to high visual demands experienced more symptoms in the upper extremities (Lie and Watten 1994). In addition, an international intervention revealed that use of appropriate corrective lenses (i.e., reduced visual demands) reduces musculoskeletal pain in the upper extremities both after one month and one year (Dainoff, Aaras, Horgen, Konarska et al. 2005a; Dainoff, Cohen and Dainoff 2005b), but it is unclear whether ergonomic adjustment of workstations was also performed in this case. In contrast, others have reported that such lenses had no influence on neck/shoulder discomfort (Aarås, Horgen, Bjørset, Ro et al. 1998; Aarås, Horgen, Bjørset, Ro et al. 2001).

In summary, the current evidence concerning a causal relationship between eye discomfort or visual demands and neck/shoulder discomfort is inconclusive, mainly due to the lack of high quality research in this area. Although cross-sectional studies are relatively inexpensive and can be performed rapidly, estimate the prevalence of an outcome, examine associations between the outcome and exposures, and suggest longitudinal studies, the fact that such studies are carried out at a single timepoint makes it impossible to determine causality (Levin 2006a; Johnson 2010). Nonetheless, even though the high prevalence of both eye-related and neck symptoms during demanding near work is well documented, considerable resources are still devoted to cross-sectional studies of these problems (Agarwal, Goel and Sharma 2013; Vilela, Castagno, Meucci and Fassa 2015; Ranasinghe, Wathurapatha, Perera, Lamabadusuriya et al. 2016; Tauste, Ronda, Molina and Seguí 2016).

In the case of prospective cohort studies, data collected at several timepoints can reveal changes in an outcome and/or exposure, and thereby indicate causality (Levin 2006b). To establish causality, an experimental design such as a randomised controlled intervention study is required (Levin 2005; 2007). One problem with such studies is that several factors are often adjusted or implemented simultaneously (e.g., improved lighting and eyewear corrections or ergonomic training and workstation adjustments) making it difficult to determine which of the factors contributes to any improvement in symptoms (Gerr, Marcus, Monteilh, Hannan et al. 2005; Brewer, Van Eerd, Amick, Irvin et al. 2006).
Visual demands and muscle activity in neck/shoulder area

As described above, neck/shoulder discomfort can be induced by sustained low-level muscle activity, and visual demand (or activity in the ocular muscles) and muscle activity in the neck/shoulder area might be related (Wiholm et al. 2007; Richter, Bänziger, Abdi and Forsman 2010). If so, high visual demands, in combination with other factors, might lead to musculoskeletal discomfort in the neck/shoulder area.

The linkage between accommodation/vergence and muscles in the neck/shoulder area has not yet been fully elucidated (cf. Richter et al. 2010). One possibility involves the tight coordination between eye and neck/shoulder muscles required to stabilise gaze (Bizzi, Kalil and Tagliasco 1971; Tu and Keating 2000; Corneil, Munoz, Chapman, Admans et al. 2008). To keep an object in focus, its image must be projected onto the centre of the fovea, with the eyes remaining stationary with respect to the object, a process in which the vestibulo-ocular reflex plays a role. When, for example, the head is turned to the right, this reflex, controlled by the extra ocular muscles, causes the eyes to move to the left (Brandt and Dieterich 1999; Kaufman et al. 2003; Wurtz 2008). The existence of a corresponding reflex or physiological mechanism involving activity of muscles that stabilise the head and/or neck during visually demanding near work remains unclear.

To date, only a few reports on the influence of visual demands on muscle activity in the neck/shoulder area have appeared. In 1987, Lie and Watten described increased muscle activity in the neck/shoulder area as visual demands increased, and, moreover, when the habitual eyewear corrections of the subjects with a history of neck/shoulder complaints were replaced by optimal corrections the muscle activity was reduced (Lie et al. 1987). One limitation of this investigation was that oculomotor responses (accommodation and vergence) were not measured objectively, but it was assumed that the subjects complied with instructions and were able to compensate for the blur induced by changing the refractive status of their eyes.

In a more recent study where oculomotor responses during demanding near work were measured with a power refractor, extensive accommodation correlated with increased trapezius muscle activity (Richter et al. 2011). However, in this case the visual task involved focusing for 5 minutes on a target of high contrast, not comparable to the demands made by everyday computer work. In addition, it was not possible to evaluate whether dynamic changes in accommodation produced a direct parallel alteration in muscle activity.
One hypothesis based on these findings is that trapezius muscle activity may be increased in association with eye-lens accommodation mediated by contraction of the ciliary muscles. Ciliary muscle activity may be linked to stabilisation of the muscles in the neck and shoulders by at least two possible rapid mechanisms: when an efferent signal is sent to the ciliary muscles, the same might also be sent to these stabilising muscles; or, alternatively, feedback from proprioceptors in the ciliary muscles might be sent to the brain, which would then deliver a motor command to these muscles (Flugel-Koch, Neuhuber, Kaufman and Lutjen-Drecoll 2009). The first of these mechanisms should involve little or no lag time, with the activity in the stabilising and ciliary muscles increasing at the same time (Kandel 2013). With the second, the activity of the stabilising muscles should increase somewhat later.

Much near work involving high visual demands also requires high attention and/or mental effort and continues for a prolonged period. Muscle activity has been reported to be elevated in response to high mental demands (Iwanaga, Saito, Shimomura, Harada et al. 2000; Thorn et al. 2007; Mehta and Agnew 2012), but the effect of the duration of the near work has not been evaluated. It is possible that the increases in muscle activity during demanding near work observed previously (cf. Lie et al. 1987; Richter et al. 2011) are mediated by a slower and indirect mechanism, rather than by a rapid and direct connection between ocular and neck/shoulder muscles.
Aims

The aims of this thesis was to determine whether neck/shoulder discomfort and trapezius muscle activity increases during visually demanding experimental near work, to investigate whether eye-lens accommodation is a mediating mechanism behind increased trapezius muscle activity, and to investigate differences between healthy individuals and those with prolonged neck/shoulder discomfort in these respects.

The two experimental laboratory studies involved either sustained focusing (accommodation) on a computer screen or changing focus between nearby and more distant targets, where the former required more accommodation. To manipulate the visual demands and promote more or less accommodation, trial lenses of different diopters were used.

The specific aims of each study were as follows:

I To examine whether neck/shoulder discomfort increase during visually demanding experimental near work requiring sustained accommodation and, if so, to characterise the factors that exert an impact in this context, as well as potential differences between individuals with and without prolonged neck/shoulder discomfort.

II To determine whether trapezius muscle activity is influenced by sustained eye-lens accommodation, sustained incongruence between accommodation and convergence, and/or prolonged neck/shoulder discomfort.

III To study whether a dynamic change in focus, alternating between nearby and more distant visual targets requiring more and less extensive eye lens accommodation, respectively, is associated with a parallel change in trapezius muscle activity, and to investigate if any effect on trapezius muscle activity is higher with trial lenses requiring more accommodation.

IV To investigate whether trapezius muscle activity increases with the duration of visually demanding experimental near work.
Methods

All four experimental studies were performed in the laboratory utilising a quantitative within-subject design. One set of data was used in Papers I, II and IV, another set in Paper III. Each subject visited the laboratory on one occasion.

Subjects

Data collection for Papers I, II and IV
The median age of the 33 healthy control subjects (27 women) was 39 years (range 20-47), while that of the 33 subjects with neck pain (27 women) was 37 years (range 19-47). The criteria for inclusion in the neck group were experience of neck/shoulder discomfort during the last 12 weeks, and a score of 10-68 points on the Neck Disability Index (NDI) (Vernon and Mior 1991).

Data collection for Paper III
The 26 subjects included 14 healthy controls (controls: mean age 26 (range 19-42), 6 men, 8 women) and 12 individuals with a history of eye and non-specific neck disorder (patients: mean age 32 (range 21-42), 3 men, 9 women). All control subjects exhibited normal aided or unaided vision. All of the patients were examined by an orthoptist and significant refractive errors corrected with spherical and/or cylindrical glasses. All such treatments were completed and all patients were free from visual symptoms for 2-3 months prior to participation. At the time of the study, all patients indicated neck problems on the NDI (mean score 9.3 (range 3-20)).

Ethical approval
All subjects provided their written informed consent prior to participation in the studies, which were preapproved by the Uppsala University Medical Ethical Review Board (Uppsala, Sweden) and conducted in accordance with the Declaration of Helsinki.
Procedure

For collection of both sets of data, the sessions began with measurement of refractive errors (Power Refractor R03, Plusoptix, Nürnberg, Germany) (Blade and Candy 2006) and selection of trial lenses for the various viewing conditions. Spherical refractive errors were corrected by the trial lenses (in steps of 0.25 D).

For electrocardiography (ECG), surface electrodes were placed to the left and right of the sixth rib, while the electrodes for electromyography (EMG) were placed bilaterally on the descending portion of the upper trapezius muscle, with a reference electrode on vertebra C7 (see Figure 1). This placement was followed by performance of three submaximal contractions for normalisation (Mathiassen, Winkel and Hägg 1995).

Thereafter, the participant was seated in an office chair and his/her posture adjusted for comfort, with support for the head and back. The upper arms hung alongside the trunk, with the hands resting on the lap. These preparations ended with a trial run of the specific visual task to be performed (see further below).

The EMG and ECG were recorded continuously during the collection of data and eye-lens accommodation monitored continuously with an auto refractor during the visual tasks. In case of the first dataset the participants rated their eye and neck/shoulder discomfort on Borg’s CR-10 scale before the experiment began (baseline) and immediately after each visual task.

Visual tasks

Data collection for Papers I, II and IV

A 7-minute standardised visual task involving sustained focusing on an image on a computer screen (viewing distance 65 cm) (Figure 1) was carried out four times under different viewing conditions, with a 3-minute period of rest preceding each session. The image was a fixation cross with a black-and white sine wave Gabor grating as background (Figure 2). At the start of the visual task, the contrast of the grating was zero, so that only the fixation cross was visible (figure 2a). This contrast was then increased (cf. Figure 2b) until the subject perceived the grating and pushed a hand-held low-force button, after which the contrast remained constant for 1.5 – 3.5 s and then began to decrease until the subject no longer perceived the grating and pushed the button again. Task instructions were: “Look at the fixation cross
and black-and-white pattern. Focus carefully on the fixation cross so that it is maximally sharp and clear at all times” (cf. Richter and Knez 2007).

**Figure 1.** Schematic illustration of the experimental laboratory set-up for collection of the first dataset.

**Figure 2.** Illustration of the Gabor grating with a) 0% contrast, b) 10% contrast and c) 60% contrast. The distance between the centers of two adjacent dark or bright stripes was 2.3 mm.

**Data collection for Paper III**

In the case of Paper III the subjects performed a 5-min near/far visual task three times, alternating their focus between a nearby (distance 15-80 cm) and a distant target (3.0 m). The mean focus time on each target was 5 s (3-7 s). Both targets consisted of an X illuminated from behind by a white colour polychromatic Light Emitting Diode (LED) (Everlight Electronics Co., Ltd., England) (cf. Figure 3). The heights of the near and far targets were 0.5 cm, and 6.8 cm, respectively. The distance to the near target was adjusted to be 5
diopters (D) away from each individual’s near point of accommodation, while the far target was placed at a fixed distance of 3 m (0.33 D).

**Figure 3.** Schematic illustration of the experimental laboratory set-up for collection of the second dataset.

Viewing conditions and trial lenses

To establish viewing conditions involving different accommodative and convergent demands, trial lenses were used. For collecting data for Papers I, II and IV the visual task was repeated four times with -3.5 D, (binocular minus, BM), -3.5 D (monocular minus, MM), +3.5 D (monocular plus, MP), or 0 D (monocular neutral, MN) trial lenses. In the case of Paper III the near/far task was repeated three times with -3.5 D (negative), +3.5 D (positive), or 0 D (neutral) binocular lenses. The individual spherical refractive error determined with the auto refractor (in steps of 0.25 D) was added to the strength of these lenses. For participants with no refractive error, a $-0.25\text{ D}$ lens was added to the neutral lenses in order to “blind” him/her to the different viewing conditions.

In all cases, the -3.5 D lenses facilitated increased accommodation and the +3.5 D lenses facilitated reduced accommodation. In Papers I, II and IV the monocular trial lenses, which do not require active convergence, isolated the effect of accommodation.

Measurements and data processing

Eye and neck/shoulder discomfort

As mentioned above, in case of the first dataset, the participants rated their eye and neck/shoulder discomfort on Borg’s CR-10 scale before the experiment began (baseline) and immediately after each visual task (see Figure 4,
left side) (Borg 1982; 1990). To capture more than one dimension of eye discomfort, he/she was asked: “To what extent do your eyes ache or feel strained?” and “To what extent do you have a burning or smarting sensation in your eyes?” (Sheedy et al. 2003). For statistical analyses, the individual mean score for these two questions were calculated. In the case of neck/shoulder discomfort, the only question was: “To what extent do you feel pain or discomfort in your neck and/or shoulders?” The region considered to be the neck/shoulders was the area defined by the Neck Pain Task Force (right side of Figure 4) (Guzman et al. 2008).

<table>
<thead>
<tr>
<th>Borg CR-10 scale</th>
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<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
</tr>
<tr>
<td>1</td>
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<td>2</td>
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<tr>
<td>3</td>
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<td>9</td>
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<td>10</td>
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</tbody>
</table>

\[\Delta\text{Eye and } \Delta\text{Neck}\]

Since the order of the viewing conditions was randomised, the median scores for eye and neck/shoulder discomfort for the control and neck groups were calculated both with respect to the order of the viewing conditions (VC1-VC4) and for each specific condition (MN, BM, MM, MP), as well as at the baseline. Thereafter, the individual changes in ratings of eye- and neck/shoulder discomfort from before the experiment (baseline) to after the fourth viewing condition (VC4) (\(\Delta\text{Eye and } \Delta\text{Neck}\) and to after the various viewing conditions (\(\Delta\text{Eye}_{\text{MN}}, \Delta\text{Eye}_{\text{BM}}, \Delta\text{Eye}_{\text{MM}}, \Delta\text{Eye}_{\text{MP}}\) and \(\Delta\text{Neck}_{\text{MN}}, \Delta\text{Neck}_{\text{BM}}, \Delta\text{Neck}_{\text{MM}}, \Delta\text{Neck}_{\text{MP}}\)) were calculated.

**Accommodation ability**

For collection of the first dataset, binocular accommodation ability was examined before and immediately after the experiment with the RAF ruler (Clement Clark International, Harlow, Essex, UK) (Rosenfield and Cohen 1996) with the eyeglass correction needed, as indicated by the power refractor.
Accommodation and convergence

During all visual tasks, the power refractor collected data on accommodation and vergence continuously at a frequency of 25 Hz (Wolffsohn, Hunt and Gilmartin 2002; Hunt, Wolffsohn and Gilmartin 2003). Since this required the eyes to be aligned with the camera, the subjects were seated leaning slightly backward in an office chair with head and back support and instructed to relax throughout the tasks. The data collected were converted into an accommodation response and for paper II into a convergence response (cf. Richter et al., 2010).

The first dataset: The individual means for the accommodation response by the dominant eye (Papers I, II and IV) and convergence response (Paper II) were calculated for each of the viewing conditions (MN, BM, MM, MP), as well as for each minute with each viewing condition (Paper IV).

The second dataset (Paper III): The individual means for the accommodation response by both eyes during the periods of near and far focusing were calculated for the most constant 1.5-s period under each viewing condition. One example of the accommodation responses during near and far focusing and the shift between these, as well as a period chosen for calculating mean accommodation are illustrated in Figure 5. For analyses of cross-correlations the raw accommodation signals were filtered at 0.05 – 3 Hz.

![Figure 5](image-url)

*Figure 5.* Representative example of the shift in accommodation between the near and far targets with the neutral trial lenses. The horizontal grey lines indicate which of the targets is turned on (near or far LED), and the vertical grey lines the shifts between the targets.
EMG and ECG

EMG activity from the descending portion of the upper trapezius muscles was monitored bilaterally with surface electrodes coated with electrode paste (Neuroline 725, Ambu A/S, Ballerup, Denmark and GEL101, BIOPAC Systems, Inc., Santa Barbara, CA, USA). These electrodes were placed 2 cm lateral of the midpoint of the line between vertebra C7 and the acromion, with a reference electrode on vertebra C7 (see Figure 1). ECG signals were collected by two electrodes (EL503, BIOPAC Systems, Inc., Santa Barbara, CA, USA) placed laterally on each sixth rib. The EMG and ECG were recorded during all visual tasks and in the case of data collection for Papers I, II and IV, during the rest period preceding each task as well.

The 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). The EMG recordings were first filtered to eliminate disturbance from heart signals (Widrow, Glover, McCool, Kaunitz et al. 1975), then converted by the root-mean-square (RMS) procedure and normalised to submaximal reference contractions, and expressed as %RVE (Reference Voluntary Electrical activity) (Mathiassen et al. 1995). Since there were no significant differences between the activities of the left and right trapezius muscles, the average of these values was used for analysis. In Papers I and II the 10th percentile of the normalised RMS values was utilised as an indicator of static trapezius muscular activity (Jonsson 1982; Thorn et al. 2007). In Papers III and IV the 50th percentile of the normalised RMS values was used as an indicator of trapezius muscle activity. ECG were used to assess the heart rate variability (HRV) as an indicator of autonomic reactivity (e.g., due to stress) during the experiments by calculating the standard deviation of the length of the periods between consecutive heartbeats (SDNN, the Standard Deviation of the beat-to-beat (NN) intervals) (Malik, Bigger, Camm, Kleiger et al. 1996).

For statistical analyses in Paper I, the individual differences in trapezius muscle activity (%RVE) between rest and the various viewing conditions, and the individual means in HRV for the various conditions were calculated.

For statistical analyses in Paper II, individual mean trapezius muscle activity in %RVE (EMG_{full 7min}) was calculated for each viewing condition. In the case of the rest periods, the individual mean trapezius muscle activities for the last minute were calculated (EMG_{rest}). For the regression model the values were log-transformed to obtain logEMG_{full 7min} and logEMG_{rest}.

For statistical analyses in Paper III, individual mean trapezius muscle activities (%RVE) during periods of near and far focusing (excluding ±1s around
target change) were calculated (see Figure 5). To compare the alteration in trapezius muscle activity between adjacent periods of near and far focusing, the individual mean value during near focusing under a given viewing condition was normalised to the individual mean far value for this same (100%) and expressed as %Far. For the cross-correlational analyses, the raw EMG signals were filtered at 20-500 Hz, RMS-transformed (0.2 s, i.e. 5 Hz), interpolated into the sampling frequency of the power refractor (25 Hz), and filtered at 0.05 – 3 Hz.

For statistical analyses in Paper IV, the individual mean trapezius muscle activities (%RVE) for each minute (1-7) of each viewing condition were computed. For the General Estimating Equation (GEE) the values were log-transformed. The individual mean in HRV was calculated for each viewing condition.

**Statistical analyses**

Signal processing was carried out with the MATLAB® software (MathWorks Inc., Natick, MA, USA) and statistical analyses with PASW 20.0 for Windows (SPSS Inc., Chicago, IL, USA). The level of significance was set at $\alpha = 0.05$.

**Paper I:** The Wilcoxon sign rank test was applied to determine whether eye and/or neck/shoulder discomfort increased during visually demanding experimental near work by comparing baseline values to those after the fourth viewing condition (VC4). The GEE for repeated measurements was used to identify factors that could contribute to the change in neck/shoulder discomfort from baseline to after the various viewing conditions (dependent variable: $\Delta$Neck$_{MN}$, $\Delta$Neck$_{BM}$, $\Delta$Neck$_{MM}$, $\Delta$Neck$_{MP}$). The independent parameters were group (control or neck), temporal order of the viewing conditions (VC1, VC2, VC3 or VC4), accommodation response (low, high or missing), refractive error (emmetrope, myope or hyperope), and cylindrical error (astigmatic or non-astigmatic). The covariates were the change in eye discomfort from baseline to after the various viewing conditions ($\Delta$Eye$_{MN}$, $\Delta$Eye$_{BM}$, $\Delta$Eye$_{MM}$, $\Delta$Eye$_{MP}$), heart rate variability and trapezius muscle activity.

**Paper II:** Repeated measures ANOVA was utilised to analyse the difference in accommodation ability before and after the experiment and differences between groups, as well as differences in the accommodation response between groups and viewing conditions. The Mann-Whitney U test was used to analyse differences in trapezius muscle activity between groups within rest and viewing conditions. The Wilcoxon signed-rank test was used to analyse differences in trapezius muscle activity between rest and during each view-
ing condition, and the Friedman test to analyse such differences between viewing conditions.

In the stepwise regression model run for each viewing condition, the dependent variables were the log-transformed individual mean trapezius muscle activities (%RVE) associated with the four viewing conditions (logEMG_{full 7 min}), and the independent variables accommodation ability, accommodation response, group (control/neck), log-transformed trapezius muscle activity during rest (logEMG_{rest}), and convergence response (for the binocular viewing condition only).

Trials with the monocular lenses (MM, MN, MP) tested whether eye-lens accommodation influences trapezius muscle activity, whereas use of the binocular lenses (BM) revealed whether incongruence between accommodation and convergence affects this activity.

**Paper III:** Paired t-tests were utilised to confirm that the accommodation responses was higher when focusing on a nearby than on a more distant target, as well as to test for differences between the groups and viewing conditions. To examine whether trapezius muscle activity was also higher when focusing on a nearby target, two analyses were performed: first, to evaluate whether activity was higher during near focusing, paired sample t-tests were run on far normalised values (%Far) for each viewing condition and group. Secondly, to investigate whether accommodation response and trapezius muscle activity vary in the same manner with time during the near-far task, the cross-correlation function (R(time shift)) was computed for each viewing condition and group. To find out whether trapezius muscle activity was higher during viewing that required more accommodation, a paired sample t-test for the different viewing conditions and groups was run on both trapezius muscle activity during near focusing and on the maximal cross-correlation.

**Paper IV:** To determine whether trapezius muscle activity increases with the duration of visually demanding experimental near work, four GEE analyses were performed, one for each viewing condition, to explore the main effect of time (min 1–7) on the dependent variable trapezius muscle activity (log-transformed values). Group (control and neck), trapezius muscle activity during rest, heart rate variability, and accommodation response were included as covariates.
Results

Paper I
In the control group the median rating of neck/shoulder discomfort was 0 (nothing at all) at baseline and 2.0 (weak) after viewing condition four. The corresponding values for the neck group were 2.5 (weak-moderate) and 5.0 (strong). The neck group rated eye discomfort with the three more demanding lenses higher (BM, MM and MP, p < 0.03), but no such difference was observed for neck/shoulder discomfort (Figure 6).

Figure 6. The change in the ratings of eye discomfort (left) and neck/shoulder discomfort (right) by the control and neck groups from baseline to after the various viewing conditions. The values presented are means with 95% confidence intervals (the bars). MN = monocular neutral, BM = binocular minus, MM = monocular minus, MP = monocular plus.

Both groups experienced more eye and neck/shoulder discomfort after the fourth viewing condition than at baseline. The GEE analysis of main effects revealed that the temporal order of the viewing conditions, accommodation response, cylindrical error, and concurrent self-reported eye discomfort all exerted an impact (p < 0.04) on the variance in neck/shoulder discomfort (Figure 7). In contrast, the group, spherical refractive error, heart rate variability, and trapezius muscle activity had no influence (p > 0.5).
Figure 7. Relationships between the mean change in the ratings of neck/shoulder discomfort from baseline to after the various viewing conditions as revealed by the GEE analysis and a) the temporal order of the viewing conditions, b) accommodation response, c) cylindrical error, and d) corresponding change in the rating of eye discomfort. VC = Viewing condition.

When interaction effects were included in the analysis, temporal order of the viewing condition x eye discomfort was found to exert a significant effect on the level of neck/shoulder discomfort (p = 0.005) (Figure 8), with participants experiencing a greater increase in eye discomfort (from baseline to the fourth viewing condition) also reporting more neck/shoulder discomfort with time. This interaction diminished the main effect of both temporal order and eye discomfort, as well as the significant main effect of the extent of accommodation response (p = 0.057).

Figure 8. The interaction effect of the temporal order of the viewing conditions and the change in the ratings of eye discomfort from baseline to after the various viewing conditions on the mean rating of neck/shoulder discomfort predicted from the GEE analysis. To illustrate the difference between small and large changes in eye discomfort, the participants were divided into the 25th percentile (dotted line, mean change 0.13, n = 17), and the 75th percentile (solid line, mean change 4.18, n = 17) using the variable ∆Eye.
Paper II

The mean accommodation ability decreased from 6.6 D before to 6.0 D after the four visual tasks (p < 0.001).

The mean accommodation responses under the four viewing conditions are displayed on the left side of Figure 9. There was a significant main effect of viewing condition (p < 0.001), but no effect of group (control/neck).

The mean trapezius muscle activity during the rest periods (white bars) and four viewing conditions (grey bars) are displayed on the right side of Figure 9. There were no differences in muscle activity between groups either during the rest periods, or during the various viewing conditions (p > 0.1). This muscle activity was higher during all of the visual tasks than during rest (p < 0.01), with no differences between viewing conditions (p = 0.38).

Figure 9. Mean accommodation response under the four viewing conditions (left side), and mean trapezius muscle activity (%RVE, right side) during the rest (white bars) and the four viewing conditions (grey bars). The error bars indicate the 95% confidence intervals. BM = binocular minus, MM = monocular minus, MN = monocular neutral, MP = monocular plus
The findings with the regression model are documented in Table 1, where p-values for all independent variables, but the coefficients and R² change for significant variables only are presented. The lack of effect of monocular viewing conditions regarding accommodation response indicates that eye-lens accommodation alone cannot account for the increase in trapezius muscle activity. In contrast, the significant impact of binocular viewing reveals that incongruent viewing affects this activity. The lack of group effect indicates that the presence or absence of neck/shoulder discomfort does not affect the response of trapezius muscle activity to visually demanding near work.

Table 1. Regression analyses of the relationships between log logEMG_{full?min} and various factors.

<table>
<thead>
<tr>
<th>Viewing condition</th>
<th>Independent variable</th>
<th>Dependent variable (logEMG_{full?min})</th>
<th>Coefficient</th>
<th>R²-change</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM</td>
<td>logEMG_{rest}</td>
<td>Accommodation response</td>
<td>0.609</td>
<td>0.327</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>Accommodation ability</td>
<td>0.109</td>
<td>0.101</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>Convergence response</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MM</td>
<td>logEMG_{rest}</td>
<td>Accommodation response</td>
<td>0.58</td>
<td>0.35</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accommodation ability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MN</td>
<td>logEMG_{rest}</td>
<td>Accommodation response</td>
<td>0.57</td>
<td>0.27</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accommodation ability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MP</td>
<td>logEMG_{rest}</td>
<td>Accommodation response</td>
<td>0.48</td>
<td>0.19</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Accommodation ability</td>
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</tr>
</tbody>
</table>

logEMG_{full?min} = log-transformed mean trapezius muscle activity (%RVE) during the visual task, logEMG_{rest} = log-transformed trapezius muscle activity during rest. BM = binocular minus, MM = monocular minus, MN = monocular neutral, MP = monocular plus.
Paper III

The mean accommodation during the periods of near and far focusing under different viewing conditions by both groups are shown on the left side of Figure 10. The accommodation responses during near and far focusing differed for all viewing conditions and both groups ($p \leq 0.05$). In the case of near focusing the control subjects demonstrated significantly higher accommodation with the negative ($p = 0.049$), but not the neutral ($p = 0.061$) or positive lenses ($p = 0.054$). Within each group the accommodation response during near focusing under the various conditions was similar ($p \geq 0.08$).

The trapezius muscle activity (\%Far) for the various viewing conditions and both groups are displayed on the right side of Figure 10. With neutral viewing this activity was higher during near than far focusing in both the control ($p = 0.007$) and patient group ($p = 0.034$), with no such differences under the other conditions ($p > 0.2$). Nor were there any significant differences between the groups.

Figure 10. Mean accommodation (left) and trapezius muscle activity (%RVE) (right) with 95% confidence intervals (the bars), by the control and patient groups, during near (grey bars) and far (white bars) focusing under the various viewing conditions (Neut. = Neutral, Neg. = Negative, Pos. = Positive).
Analysis revealed that for the control group the maximal cross-correlation for the neutral \((p = 0.002)\) and the positive \((p = 0.012)\) viewing differed significantly from zero, although the estimated time shift did not (see Figure 11). With the negative viewing and for the patient group, none of the maximal cross-correlations differed significantly from zero. Under the positive viewing condition the maximal cross-correlation for the control group was higher \((p = 0.008)\).

*Figure 11.* Mean cross-correlation curves (black lines) and the 95% confidence intervals (grey lines) for the control group under neutral, negative, and positive conditions of viewing.

In the case of the control group, trapezius muscle activity during near focusing (in %Far) was higher with neutral than with negative viewing \((p = 0.013, \text{ cf. the right side of Figure10})\). With the patient group the muscle activity was the same under the various viewing conditions, nor were there any significant differences between viewing conditions with respect to maximal cross correlation for either group.
**Paper IV**

Figure 12 shows the mean trapezius muscle activity per minute during rest and under the various viewing conditions. The GEE analyses revealed an elevation in trapezius muscle activity with time ($p < 0.01$), as well as an effect of the corresponding muscle activity during the preceding rest period ($p < 0.001$) under all four viewing conditions. The extent of accommodation exerted a significant effect under the two viewing conditions that required a pronounced accommodation response ($p = 0.007$ during BM and 0.048 during MM). In the neutral condition (MN) heart rate variability had a very small, but significant effect ($p = 0.043$). There were no group differences under any of the viewing conditions.

**Figure 12.** Mean trapezius muscle activity (% RVE) during rest (white circles) and the 7-min visual task (black circles) as a function of time under the four viewing conditions. The error bars depict the 95% confidence intervals. BM = binocular minus, MM = monocular minus, MN = monocular neutral, MP = monocular plus.
Discussion

The aims of this thesis was to determine whether neck/shoulder discomfort and trapezius muscle activity increases during visually demanding experimental near work, to investigate whether eye-lens accommodation is a mediating mechanism behind increased trapezius muscle activity, and to investigate differences between healthy individuals and those with prolonged neck/shoulder discomfort in these respects.

In Paper I both healthy individuals and those with prolonged neck/shoulder discomfort experienced increased neck/shoulder discomfort, with individuals experiencing a greater increase in eye discomfort also reporting more neck/shoulder discomfort with time. In Paper II the accommodation response associated with the near work appeared to be unrelated to the increase in muscle activity, whereas incongruence between accommodation and convergence exerted a significant and similar impact on this activity in both groups. In Paper III trapezius muscle activity was higher during near focusing (requiring greater accommodation) than far focusing, but only with the neutral viewing. Furthermore, accommodation and trapezius muscle activity co-varied with time, but only with the neutral and positive viewing and by the control subjects. In Paper IV trapezius muscle activity increased significantly with time under all viewing conditions with no differences between the groups.

In summary, the main findings are that both neck/shoulder discomfort and trapezius muscle activity increased during the visually demanding experimental near work and that the elevation in muscle activity appears to be unrelated to accommodation response. With respect to neck/shoulder discomfort and muscle activity, near work affects healthy individuals and those with prolonged neck/shoulder discomfort in a similar manner, nevertheless, individuals experiencing a more pronounced increase in eye discomfort reports more neck/shoulder discomfort with time.

Neck/shoulder discomfort during near work

Among both healthy individuals and those with prolonged neck/shoulder discomfort, the visually demanding experimental near work resulted in more
neck/shoulder discomfort, which increased from “nothing at all” at baseline to “weak” after the fourth viewing condition in the control group, and from “weak-moderate” to “strong” in the neck group. The duration of the near work explained most of the rise in neck/shoulder discomfort, with the scores increasing with each successive visual task. Concurrent eye discomfort, as well as the extent of accommodation and presence of astigmatism, both of which influence the visual demand, affected neck/shoulder discomfort, whereas the level of trapezius muscle activity did not. Participants experiencing a more pronounced increase in eye discomfort also reported more neck/shoulder discomfort with time. In addition, those with neck problems reported a greater increase in eye discomfort than the control subjects when viewing through the more demanding lenses (BM, MM and MP).

The duration of computer work, especially time spent using mouse or keyboard, is often considered to be a potential risk factor for musculoskeletal pain (Punnett and Bergqvist 1997; Brandt, Andersen, Lassen, Kryger et al. 2004; Cagnie et al. 2007; Ye, Abe, Kusano, Takamura et al. 2007; Eltayeb, Staal, Hassan and de Bie 2009; Hakala, Saarni, Punamaki, Wallenius et al. 2012; Huysmans, IJmker, Blatter, Knol et al. 2012). Even though our participants were exposed only to visual demands, they experienced neck/shoulder discomfort. As observed earlier in field studies, the level of eye discomfort depends on the duration of the near work (Portello et al. 2012; Toomingas, Hagberg, Heiden, Richter et al. 2013). Here, in a laboratory setting, the degree of self-reported eye discomfort caused by the visually demanding near work explained parts of the variation in neck/shoulder discomfort. Moreover, a more pronounced increase in eye discomfort was associated with a greater rise in neck/shoulder discomfort with time (Figure 8).

Here, we varied the visual demands associated with the task with different lenses that facilitate more or less accommodation. Even though these different lenses led to significant differences in accommodation response (cf. Figure 9) the visual condition per se (i.e. BM, MM, MN, MP) did not affect the rating of neck/shoulder discomfort (cf. Figure 6). This lack of an effect might reflect the fact that certain participants did not follow the instructions fully. For instance, although accommodation stimulus with the minus lenses (BM and MM) was 5 D, the overall mean value were 3.1 D and 3.4 D, the standard deviations close to 2 D, and the ranges 9.8 D and 7.3 D respectively. Thus, some of the participants accommodated as instructed, whereas others did not accommodate at all.

Since the variation in viewing condition (i.e. BM, MM, MN, MP) did not reflect the actual accommodation, objective measures of the accommodation response were included in the GEE analyses, revealing that the participants who accommodated more also experienced more neck/shoulder discomfort.
In addition, the astigmatic refractive errors for certain participants were not corrected for, resulting in a higher visual demand compared to non-astigmatic subjects. Indeed, the GEE analyses showed that uncorrected astigmatism also increased neck/shoulder discomfort (see Figure 7c). The results of the few intervention studies concerning the effect of reducing visual demand, e.g., appropriate corrective lenses, on neck/shoulder discomfort have been inconsistent, showing either reduction in (Dainoff et al. 2005b; Hemphälä, Nylen and Eklund 2014) or no effect on neck pain (Aarás et al. 2001). Previous research has demonstrated that both uncorrected and induced astigmatism aggravate eye related symptoms (Wiggins et al. 1992; Rosenfield et al. 2012), but to date no studies on associations between astigmatic error and neck/shoulder discomfort appeared to have been published.

In summary, neck/shoulder discomfort increased during the visually demanding experimental near work in a manner dependent on the duration of this work. The visual demands as reflected here in extensive accommodative responses and uncorrected astigmatic error, and concurrent eye discomfort especially in combination with longer duration, all exerted an impact. Since individuals already suffering from prolonged neck/shoulder symptoms were more prone to develop eye discomfort, they might also experience aggravated neck/shoulder discomfort when visual demands are high.

Trapezius muscle activity during near work

The visually demanding experimental near work elevated trapezius muscle activity above the level observed during the rest periods (Paper II), to a greater extent during near than during far focusing with the neutral viewing (Paper III) and with the duration of the near work (Paper IV). This increase in muscle activity was independent of the level of visual demand, and unrelated to prolonged neck/shoulder discomfort.

In Paper II, no relationships between the monocular viewing, which isolated the effect of accommodation during sustained focusing, and trapezius muscle activity was found under any of the monocular viewing conditions. In addition, no pronounced effects were found either on muscle activity (Papers II and III), or cross-correlation between accommodation and muscle activity (Paper III), or on the increase in muscle activity with time (Paper IV) under viewing conditions that required more accommodation. The lack of a significant difference in trapezius muscle activity during near focusing under the various viewing conditions (cf. the right side of Figure 10) could be related to the lack of any significant difference in accommodation response under these conditions (cf. left side of Figure 10). Trapezius muscle activity was,
however, greater during near focusing (increased accommodation) than during far focusing (reduced accommodation) but only under the neutral viewing condition (right side of Figure 10). There was also a significant cross-correlation between accommodation and muscle activity, but only for the control group with the neutral and positive viewing.

Even if trapezius muscle activity during demanding near work is independent of accommodation, incongruence may have an effect on this activity. Incongruence occurs when conflicting demands are placed on accommodation and convergence, e.g., the binocular minus lenses (Paper II) required increased accommodation, while convergence remained fixed on the target. Such incongruence can cause work-related visual fatigue (Ukai and Howarth 2008) and in the clinic, convergence insufficiency is associated with musculoskeletal discomfort (Sucher 1994; Borsting, Rouse, Deland, Hovett et al. 2003). It has also been proposed that incongruence affects postural stability, which in turn could modify the activity of neck muscles involved in postural control (Kapoula, Gaertner and Matheron 2012). Here, in Paper II, incongruent oculomotor demands were significantly related to trapezius muscle activity (cf. Figure 4 BM in Paper II). Similarly, Richter and colleagues found linear relationships between accommodation and muscle activity under two conditions of incongruent viewing (Richter et al. 2010). At the same time, the findings documented in Paper III do not support such a relationship, since there was no significant co-variation with the most incongruent trial lens (negative) for either group. This may reflect the fact that incongruence was present during both near and far focusing and that merely the presence, rather than the level, of incongruence may be what is important.

Altogether, elevation of trapezius muscle activity appears to be unrelated to accommodation and thereby not directly linked to ciliary muscle activity, as proposed in the Introduction. If this were the case, the relationship between accommodation and muscle activity observed in paper II would be expected to also be present when viewing with the monocular minus lenses, which involved accommodative responses similar to those under the binocular condition. In addition, despite the significant differences in the accommodation responses under the various viewing conditions reported in Papers II and IV, no differences between these conditions with respect to muscle activity were evident in any of the studies, in agreement with the results of Richter and colleagues (2010).

Moreover, a pronounced effect of negative viewing on both trapezius muscle activity and cross correlation compared to the neutral and positive conditions, would be likely but was not observed (Paper III). At the same time, this lack of effect might be explained by the small differences in accommodative responses under the various conditions, as well as the fact that the
responses under the neutral and positive conditions differed from the accommodative stimulus, resulting in similar mean differences in accommodation during near and far focusing under the different conditions (cf. the left side of Figure 10). This suggests that the accommodation response originated primarily from convergence. Finally, during near focusing under the negative condition, the accommodation response was greater, trapezius muscle activity (%Far) lower, and cross-correlation non-significant, all of which contradict any direct link.

Prolonged neck/shoulder discomfort did not affect the level of trapezius muscle activity during the experimental near work, in line with previous research on work involving low biomechanical exposures (Holte and Westgaard 2002; Sjøgaard, Søgaard, Hermens, Sandsjö et al. 2006). However, experimental computer work designed to induce psychological stress has been reported to increase muscle activity for subjects with self-reported neck/shoulder discomfort (Thorn et al. 2007; Larsman, Thorn, Søgaard, Sandsjö et al. 2009). In the investigation of muscle activity during dynamic changes in accommodation reported in Paper III, the maximal cross-correlations for the control group with the neutral and positive trial lenses differed significantly from zero, with no such differences for the patients. This could be due, at least in part, to the heterogeneity of the patient group, with visual symptoms from various causes and self-reported neck/shoulder of unknown origin. Altogether, there is insufficient evidence for an altered effect of visually demanding near work on the trapezius muscle activity of individuals with prolonged neck/shoulder symptoms.

**Possible explanations for the increase in muscle activity**

The elevated trapezius muscle activity associated with the experimental near work might reflect an enhanced need for eye-neck (head) stabilization when focusing on a nearby target. As described in the Introduction, keeping an object in focus requires that it is projected onto the centre of the fovea and that the eyes remain stationary with respect to the object. When focusing on a nearby target, movement of the head in the frontal plane causes a relatively large change in the visual angle, while for a distant target, this angle will remain virtually unchanged. A large change could result in increased muscle activity, especially in muscles acting as primary stabilizers of the neck.

Indeed, this was observed with the neutral trial lens in Paper III (cf. the right side of Figure 10). Further, such an effect would explain the co-variation with the positive lens observed in this same paper, since viewing a nearby target through a positive magnifying lens augments alteration in visual angle associated with head movement and thereby the need for stabilisation. This suggestion is in line with interactions observed between extra-ocular muscles and the neck muscles during a shift in gaze, both when the head is fixed and
moving (Bizzi et al. 1971; Andre-Deshays, Berthoz and Revel 1988; Andre-
Deshays, Revel and Berthoz 1991; Bexander, Mellor and Hodges 2005). Howev-
er, in Paper II there was no relationship with the positive lens so that the
suggested mechanism of eye-neck (head) stabilisation appeared to be absent.
At the same time, individual accommodation responses during the 7-
min sustained focusing with the positive showed little variation, with a group
mean of approximately 1 D, indicating that the blur induced was too difficult
to overcome and that the subjects might have given up. Consequently, ac-
commodation might have reached the resting point, reducing the need for
eye-neck (head) stabilisation to a minimum.

Moreover, Kapoula and colleagues (2012) suggest that lenses that affect
either accommodation or convergence reduce the postural stability and might
thereby increase the activity of stabilising neck muscles. This proposal is
not, however, supported by Paper III, where the negative lens requiring in-
creased accommodation exerted no effect on either the cross-correlation or
muscle activity. As discussed above in conjunction with incongruent view-
ing, this lack of effect might also derive from the fact that the same lenses
affecting accommodation were used during both near and far focusing,
which might have diminished any effect.

The requirement for eye-neck (head) stabilisation during near focusing
and/or shifts in gaze may also be related to visual attention. Visual attention
is defined as a set of cognitive operations designed to select relevant and
filter out irrelevant information from the visual field (McMains and Kastner
2009). When visual attention requires shifts in gaze, the activity of muscles
rotating the neck increases, even when neck rotation is absent (Corneil et al.
2008). Furthermore, during a visual search task requiring no head or neck
movement, the trapezius muscle activity was significantly higher than at
baseline or during a control task that simply involved focusing on a spot on a
computer screen (viewing distance 50 cm) for five minutes (Iwanaga et al.
2000).

In Paper III the visual task required visual attention and a change in the
depth of gaze in, but involved no lateral gaze shifts or disturbances. Howev-
er, with the positive trial lens, the far target was more blurred and would
therefore require more visual attention, whereas focusing on the near target
produced the greatest trapezius muscle activity. In Papers II and IV although
the visual stimulus was fixed, the room was dark, and there were no lateral
distracting visual stimuli, visual attention was required in order to comply
with the task. The participants needed more contrast to detect the black- and
white Gabor grating at the end of the task (cf. Figure 4 in Paper IV) and
probably had to invest progressively more visual attention to maintain per-
formance. The increase in muscle activity with time shown in Paper IV may
have been triggered by this elevated need for visual attention. In connection with regular computer work, involving high visual attention together with recurrent shifts in gaze, this effect might be more pronounced.

The increase in muscle activity observed here could also be associated with stress. Several experiments have found that mental stress or mentally demanding tasks can stimulate muscle activity independent of physical load (Iwanaga et al. 2000; Lundberg, Forsman, Zachau, Eklöf et al. 2002; Shahidi, Haight and Maluf 2013) and a meta-analysis concluded that simulated workplace stress induced cognitively, emotionally or by the pace of work increases muscle activity in the neck/shoulder region (Eijckelhof, Huysmans, Bruno Garza, Blatter et al. 2013). Even though our visual tasks were not designed to induce stress, they required mental effort and attention. In addition, the participants visited the laboratory only once and were thus unfamiliar with both the task and measuring equipment. Therefore they might have perceived the situation as stressful and reacted accordingly, e.g., with increased muscle activity. Measurements of heart rate (not shown) do not, however, support this proposal, and in Paper IV heart rate variability was to a small extent related only to the increase in muscle activity during the neutral viewing.

Methodological strengths and limitations

One strength of the studies described here is objective measurement of eye lens accommodation during the near work tasks and simultaneous measure of trapezius muscle activity with EMG.

However, our methodology has certain limitations. Since the eyes had to be aligned with the auto refractor, the head needed to be stationary. Therefore, the subjects were seated leaning slightly backward, with head and back support, which might have influenced muscle activity. For instance, stabilisation of the head might reduce the need for gaze stabilisation during the visually demanding near work, thereby diminishing eventual effects on muscle activity, which might explain the low values on trapezius muscle activity observed in all our studies. Even though the participants were instructed to sit relaxed, they were also encouraged to maintain the static posture. On the other hand, our ambition was to eliminate as many confounding variables (e.g., postural and repetitive demands) as possible in order to evaluate the effect of visually demanding near work in itself.

A second potential limitation concerns the age distribution of our subjects. The accommodation ability of humans gradually declines from childhood until about 50 years of age (Kaufman et al. 2003). In Papers I, II and IV,
measurements of accommodation ability before the visual tasks revealed that only 43 of the 66 subjects were capable of overcoming the blur induced by the minus lenses (i.e., had an accommodation ability $\geq 5$ D) and all of those lacking this ability were at least 37 years old. In addition, the auto refractor cannot collect data when the pupils are too strongly constricted (i.e., with a diameter $\leq 2.8$ mm) and during accommodation the pupil constricts in order to improve the depth of focus. This might have resulted in underestimation of the mean accommodation response, even for highly compliant participants with the ability to overcome the blur.

The choice to record EMG activity from the upper trapezius muscle has both advantages and disadvantages. This muscle can be easily monitored with surface EMG electrodes, is a common site for work-related pain, and has been the focus of much research on EMG signals in relationship to sedentary work, such as on the computer (Sommerich, Joines, Hermans and Moon 2000).

On the other hand, the trapezius muscle is not primarily involved in stabilisation of the neck, but is considered mainly to stabilise and move the scapula (Inman, Saunders and Abbott 1996; Sommerich et al. 2000). Accordingly, if the relationships observed here were due to eye-neck (head) stabilisation, there should be a similar or even more pronounced effect on muscles acting as primary stabilisers of the neck, such as deep cervical flexor and extensor muscles (Nolan Jr and Sherk 1988; Mayoux-Benhamou, Revel, Vallée, Roudier et al. 1994). Unfortunately, these muscles are difficult to monitor non-intrusively (Falla, Jull, O’Leary and Dall'Alba 2006). Furthermore, the trapezius muscles are sensitive to attention-related mental demands and responsive to stressful situations (Lundberg, Kadeffors, Melin, Palmerud et al. 1994; Waersted and Westgaard 1996; Iwanaga et al. 2000; Willmann and Bolmont 2012) and mentally induced stress might activate low-threshold motor units in these muscles (Lundberg et al. 2002).

The generalisability of the present studies is limited, since the experimental near work tasks differ from regular computer work. In Papers I, II and IV the duration of work was very short (7 min.), the participant’s head and back were supported, and they were instructed to sit relaxed without moving during the experiment. The mean accommodation response with the minus lenses (approximately 3 D) corresponds to a viewing distance of 0.3 m, which puts a greater load on the visual system than the 0.50 – 0.85 m distance to screen recommended in connection with computer work (Rempel, Willms, Anshel, Jaschinski et al. 2007). At the same time, use of tablets and smart phones often involves a shorter viewing distance (Bababekova et al. 2011). Moreover, the near/far task in Paper III was not designed to mimic normal near work conditions at all. In summary, the results should be trans-
lated and interpreted with caution in populations performing near work on a computer screen.

Conclusion

Visually demanding experimental near work elevates both neck/shoulder discomfort and trapezius muscle activity in a time-dependent manner. The visual demands (here, the extent of accommodation and presence of astigmatism) and concurrent eye discomfort affect the degree of neck/shoulder discomfort. In addition, participants who experience a more pronounced increase in eye discomfort also develop more neck/shoulder discomfort with time, and since individuals already suffering from prolonged neck/shoulder symptoms were more prone to develop eye discomfort, they might also experience more neck/shoulder discomfort when visual demands are high. It is unlikely that the increase in trapezius muscle activity was mediated by eye-lens accommodation, since the accommodation response under the various viewing conditions, and with monocular viewing did not affect this activity. Even if a direct link between the accommodation-/convergence system and trapezius muscles cannot be entirely ruled out, the increase in muscle activity observed here may be due to a combination of high visual attention and enhanced requirement for eye-neck (head) stabilisation. The present findings highlight further the importance of good visual conditions in connection with visually demanding near work to reduce musculoskeletal disorders, especially for individuals already suffering from prolonged neck/shoulder symptoms.
Future research

This thesis addressed high prevalence of musculoskeletal symptoms in the neck/shoulder region in occupations involving more and more sedentary computer-based visual near work. Clearly much more research in this area is motivated.

For example, there is a need for additional experimental studies involving realistic near work tasks that place realistic visual demands e.g., of longer duration, and utilising equipment that allow objective measurement of these demands (e.g., accommodation and convergence) even when the head is free to move.

It would also be of interest to investigate the potential relationship between convergence demands and both muscle activity and discomfort in the neck/shoulder region. In this context, equipment already available for treating patients with a reduced vergence capacity could be utilised to produce dynamic changes in vergence eye movements (Ramsay, Davidson, Ljungblad, Tjärnberg et al. 2014).

The present evidence for a causal relationship between neck/shoulder discomfort and eye discomfort, on the one hand, and/or visual demands, on the other, is not conclusive, and there is a need for prospective cohort and/or randomised controlled intervention studies. For example it would be of interest to follow workers exposed to different visual demands, or to conduct a within-subject intervention study designed to compare e.g., the effects of habitual and customised computer vision eyeglasses. The web-based risk assessment method for visual ergonomics in workplaces currently being developed (AFA Dnr: 130166) can later on be used in prospective or intervention studies to collect valid and reliable data on the visual environment and visual and musculoskeletal problems (Hemphälä, Zetterberg, Lindberg, Heiden et al. 2015).
The PhD candidate’s contribution

Paper I: collected and managed all data, determined appropriate statistical analyses and performed all statistical analyses, drafted the manuscript, and coordinated and conducted revisions following co-author input.

Paper II: collected and managed all data, collaborated to determine the appropriate statistical analyses and performed all statistical analyses, drafted the manuscript, coordinated and conducted revisions following co-author input, and submitted the manuscript.

Paper III: collaborated to determine and perform the appropriate statistical analyses, drafted the manuscript, coordinated and conducted revisions following co-author input, and submitted the manuscript.

Paper IV: collected and managed all data, collaborated to determine the appropriate statistical analyses, and provided substantial feedback during the manuscript preparation and revisions.
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Introduktion: Muskelrelaterade besvär i nack- och skulderområdet är vanligt förekommande, framförallt hos individer som utför synkrävande datorarbete. En orsak till sådana besvär anses vara långvarig lågintensiv aktivitet i dessa muskler. Det är i dagsläget oklart om de belastningar som synsystemet utsätts för vid synkrävande arbete bidrar till ökad muskelaktivitet i nack/skulderregionen. 

Syfte: Syftet var att undersöka om experimentellt synkrävande närarbete påverkar muskelaktivitet och besvär i nack/skulderregionen, och att undersöka om aktivitet i trapezius muskeln (kappmuskeln) påverkas av ögats ackommodation, d.v.s. när linsens brytkraft förändras för att se skarpt på nära håll.


Resultat: Det synkrävande arbetet ökade både de självskattade nack/skulderbesvären och muskelaktiviteten i trapezius. De personer som upplevde en högre ökning av ögonbesvär (i förhållande till baslinjen), rapporterade också mer nack/skulderbesvär över tid. Det var varken någon signifikant skillnad i grad av muskelaktivitet mellan synuppgifterna, eller något signifikant samband mellan monokulär ackommodation och muskelaktivitet.

Slutsats: Resultaten indikerar att ögats ackommodation, i sig, inte påverkar muskelaktiviteten i trapezius. Ökad muskelaktivitet i nack/skulderregionen i anslutning till synkrävande arbete kan istället bero på en kombination av höga krav på visuell uppmärksamhet och ett ökat behov av att stabilisera ögonen (huvudet) i förhållande till objektet i fokus (t.ex. texten på en bildskärm). Eftersom resultaten tyder på att synkrävande närarbete leder till ökade besvär i nack/skuldraregionen över tid, är det viktigt att utforma arbetsplatser och synkrävande arbetsuppgifter (t.ex. vid datorn) på ett sätt som främjar visuell hälsa.
References


A doctoral dissertation from the Faculty of Medicine, Uppsala University, is usually a summary of a number of papers. A few copies of the complete dissertation are kept at major Swedish research libraries, while the summary alone is distributed internationally through the series Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Medicine. (Prior to January, 2005, the series was published under the title “Comprehensive Summaries of Uppsala Dissertations from the Faculty of Medicine”.)