Temporal Dependence of Trapezius Muscle Activation during Sustained Eye-Lens Accommodation at Near

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Abstract. In this experimental study different levels of oculomotor load were induced via optical trial lenses. The aim was to investigate the temporal dependence of a moderate visual load on trapezius muscle activity. Trapezius muscle activity was measured with bipolar surface electromyography (EMG). Sixty-six subjects with a median age of 36 (range 19–47, std 8) viewed a black and white Gabor grating (5 c/deg) through 0 D, and -3.5 D lenses, in periods of 7-min. An auto refractor was used to continuously sample data on eye-lens accommodation during the vision tasks. Response-diopters were used as a dichotomous high/low accommodation grouping variable. For these groups EMG amplitudes during minutes 1-7 per each lens trial were studied separately with Generalized Estimating Equations (GEE). The analysis results showed significant increases in trapezius muscle activity over time for both viewing conditions. For the binocular -3.5 D condition response-diopters gave a significant positive contribution to the EMG amplitude. The results indicate that sustained eye-lens accommodation at near, during ergonomically unfavorable viewing conditions, may increase the risk for trapezius muscle myalgia.

Keywords: Visual ergonomics, Gaze stabilization, Electromyography, Eye-lens accommodation, Computer work, Neck.

1 Introduction

Disorders of the visual and musculoskeletal systems are major public health problems affecting substantial proportions of the general population in their work, daily living and social life. National Institute for Occupational Safety and Health (NIOSH) reports that over 80% of those who work with computers suffer from eye and/or muskuloskeletal complaints. Despite the fact that many causes have been identified which is responsible for neck and upper extremity pain, the underlying mechanisms are still poorly understood. The point of departure for the present research is the notion that accommodative/vergence eye movements are intrinsically integrated with head and scapular area muscle functionality and that the coupling between these effectors lay the foundation for visually mediated musculoskeletal mechanisms.

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In order to perceive small details in the surround, e.g. an alphanumerical character displayed on an electronic screen, the light has to be appropriately refracted. The process of adjusting the curvature of the crystalline eye lens, which brings images into sharp focus in the plane of the retina, is called accommodation. The accommodative response consists of a tightly coupled triad of eye movements: dioptric (D) adjustment of the crystalline eye lens; convergence/divergence of both eyes toward the locus of fixation; and pupillary constriction/dilatation. The accommodative system of the eye adjusts the curvature of the lens, thereby changing its refractive power, allowing the formation of a clear retinal image of an object located at a different distances than the present. This reaction is controlled by the ciliary muscle which changes the curvature of the lens.

Accommodation and vergence mechanisms in the visual system in all likelihood form one biologically plausible pathway by which augmentation of eye-muscle activity cause an increase in neck/shoulder muscle activity; over time, this could develop into discomfort, pain or ache. A sufficient description of the mediating sensorimotor events may be part of an answer to the question about why some types of neck pain occur. Hence, such mechanisms, if properly understood, have the potential to explain how and why augmented eye muscle activity leads to increased neck/shoulder muscle activity.

Recent work on trapezius muscle activation, as measured with surface EMG, has shown that brief and extended periods of large amplitudes of ocular accommodation, when the ciliary muscle is highly contracted, are coupled to an increase in static trapezius muscle activity level [1, 2]. The previous results showed, more specifically, that increasing the tone of the ciliary muscle, by placing an optical minus lens in front of both eyes and at the same time seeing to that the lack of focus incurred is compensated for by binocularly increasing eye-lens accommodation, was significantly coupled to a bilateral increase in trapezius muscle activity.

These and other results together suggest that sustained eye-lens accommodation has the ability to trigger a postural stabilization response. The exact mechanism(s) linking eye-neck/scapular muscle activity with one another however remains elusive. So far the temporal aspects of exposure to deficient visual ergonomics have not been addressed. The relationships between ciliary muscle load and trapezius muscle activation levels, previously observed on a group level [1, 2], could be related to time. However, the dimension of time was discarded from the results communicated in Richter et al. [1, 2]. Against this background, the purpose of the present study is to investigate temporal dependence of trapezius muscle activity during sustained eye-lens accommodation at near.

The first hypothesis stated that trapezius muscle activation levels, as measured by surface EMG, increase over time during visually demanding near work (hypothesis 1). An increase in EMG is hypothesized to result from the visually demanding near work, since they invoke sustained mental attention to the task [3, 4], and sustained eye-lens accommodation. Excess effort to achieve required accommodation may be triggered by mental/physical task demands [5, 6] and carry over to the musculoskeletal system. The temporal unfolding of trapezius muscle EMG activity, as a result of experimentally controlled intensive near work, is generally unknown at present.

The second hypothesis stated that trapezius muscle activation levels are modulated by response-diopters, such that more eye-lens accommodation than what is called for relative an ergonomically appropriate work condition, leads to more EMG and vice versa (hypothesis 2). Response-diopters, an indirect measure of ciliary-muscle load, may be assumed to represent an idiosyncratic characteristic which, if high in a relative sense (e.g. due to uncorrected hypermetropia, inappropriately close working distance to visual display, etc), could cause an increase in trapezius muscle activation [1, 2].

2 Methods

2.1 Participants

Sixty-six participants (median age 38, range 19-47, 54 females and 12 males) were recruited, 33 with neck pain and 33 healthy controls. To exclude participants with eye diseases, the participants were examined by a licensed optometrist. No one was excluded due to eye diseases. All participants were recruited through advertisement. Informed consent was obtained from each participant. The study was approved by the Uppsala University Medical Ethical Review Board, Uppsala, Sweden (2006:027).

2.2 Visual Task

The vision task consisted of 7-min of accommodation/convergence on a contrast varying Gabor grating displayed on a computer screen (Sony F520 CRT monitor and a VSG video board. Cambridge Research System Ltd, Rochester, UK). The contrast threshold of the grating was determined using the von Békésy tracking method. The target consisted of a fixation cross on a black- and white sine wave Gabor grating. The contrast of the Gabor grating varied throughout the task (Contrast=(Lmax-Lmin)÷(Lmax+Lmin), L = luminance). Distance to screen was 0.65 m (1.5 D) and the centre of the grating was placed in the midline of the eyes, with the gaze angle approximately 15° downwards. For maximal stimulation of accommodation, the spatial frequency of the Gabor grating was set to 5 c/deg. Before the vision task started, the contrast of the Gabor grating was zero and only the fixation cross was visible. To start the vision task, the volunteers pushed a hand-held, low-force button and the contrast of the grating increased (speed 0.8 percent/s.). When the volunteers perceived the grating, he/she pushed the button and the contrast froze for a short period. After a pause of random length (1.5-3.5 s.), the contrast of the grating decreased. When the grating became invisible to the participant, he/she pushed the button. This was repeated for seven minutes. With each response, the subjects caused a reversal of the contrast course and the computer recorded each level of contrast at which this occurred. A standardized task instruction was used: “Look at the fixation-cross and the black-and-white Gabor grating. Carefully focus on the fixation cross so that it is maximally sharp and clear at all times”. Accommodation stimuli in each of the two 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). The accommodation response varied and was assessed with an auto refractor (Power

Refractor R03, Plusoptix, Nürnberg, Germany). Accommodation stimuli were 5.0 D in the minus-lens condition and 1.5 D in the neutral-lens condition. To overcome the experimentally induced blur in the minus-lens condition and obtain a maximally sharp image of the Gabor grating, the participant had to sustain ciliary contraction corresponding to a 5 D change of optical power in the eye-lens.

2.3 Electromyography and Electrocardiography

EMG and ECG were recorded 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 decrease disturbances from heart signals on raw EMG. 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 next 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 subsequently 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.

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 50th percentile of the normalized RMS-values for each minute was chosen as the parameter of the muscular activity level. For the rest period, minutes one, two and three were first used in order to assess the stability of the EMG activity. In the main analysis the average rest period EMG across min 1-3 was thereafter used. For the vision tasks minutes one through seven (min 1-7) was used. Hereafter, these 50th percentiles from rest and vision task will be referred to as EMG_{rest} (average of min 1-3) and EMG_{task} (min 1-7), respectively. A logarithmic transform was applied on EMG_{rest} and EMG_{task} prior to the statistical analysis in order to correct for a tilt in the distribution of data which was skewed with most participants exhibiting very low or low activation levels with a tail in the right direction.

ECG was also used to assess the heart rate variability (HRV) as markers of autonomic reactivity (e.g. as due to arousal) during the experiments. Analyses of the variation of intervals between consecutive heartbeats have been shown to quantify the autonomic heart regulation and the balance between sympathetic and parasympathetic activation (Task Force, 1996). Because of the very short periods as basis for the HRV calculation, standard deviation of the times between the R-peaks, the NN intervals (SDNN, standard deviation of RR intervals) was the chosen variable. SDNN is simple to calculate and should, in comparison to the frequency band variables, make use of the one-minute data in a more efficient way.

2.4 Statistical Analysis

General Estimating Equation (GEE) was used to analyze the EMG data. GEE provides a general framework for analysis of polychotomous continuous data and relaxes several key assumptions of traditional regression models [7, 8, 9].

The original data consisted of 66 subjects x 7 minutes thus 462 data points. After outlier removal (<5%) residuals from the different factor in the model were in acceptable agreement with the normal distribution (i.e., with the great majority of logEMG-values within ±1.96 std). The requirement of homogeneity of variance was satisfactorily met.

All statistical tests on EMG were run on a mean of left and right trapezius using the 50th percentile %RVE. Statistical analyses were performed with PASW 18.0 for Windows (SPSS Inc., Chicago, IL, USA).

Rest-Period. To examine if time (min 1-3) was a mediating cause behind progressively increased trapezius muscle activation levels across time, two Generalized Estimating Equations (GEE) models were tested, one for each rest period immediately preceding the visual tasks. The purpose was to ascertain that the trapezius muscle was relaxed and that the EMG activity did not exhibit an increase in activity that could be due to biomechanical effects (which then would be a confounding variable when the effect of the vision task was analyzed).

Visual Task. To examine if oculomotor load was a mediating cause behind progressively increased trapezius muscle activation levels across time, two Generalized Estimating Equations (GEE) analytic approaches were utilized, one for each experimental lens condition (±0 D, and -3.5 D). A dichotomous variable, $RD_{low/high}$, in each experimental lens condition was set to 'low' for those whose average response diopter was below the mean level for that lens, and to 'high' for those above the mean level. This indirect measure of oculomotor load was analyzed together with trapezius muscle EMG over minutes 1-7 together with several additional independent variables. In the initial analytic step GEE tested the effect of the following independent variables on $logEMG_{task}$: $logEMG_{rest}$, SDNN, time, and $RD_{low/high}$. In the final analytic step the two GEE models was restricted to include only those independent variables which passed the threshold for significance ($p<0.05$). The variance contribution from $logEMG_{rest}$ on $logEMG_{task}$ was included in the models in order to render the dependent variable less biased by musculoskeletal activity unrelated to the experimental treatment. The effect of SDNN was assessed in order to control for autonomic nervous system activation which could be a potential confounding variable. The measures of time included minutes (minutes 1-7) within trial-lens condition.

3 Results

3.1 EMG Activity during Rest (min 1-3)

No effect of time (min 1-3) or trend thereof on logEMG activity was evident in any of the rest periods preceding the two vision tasks ($p>0.05$).

3.2 EMG Activity during Vision Task (min 1-7)

The activation levels of trapezius muscle activity ($logEMG_{task}$) was related to baseline activity ($logEMG_{rest}$) in both lens conditions ($p<0.001$). Time impacted on $logEMG_{task}$ in both lens conditions ($p<0.001$). Response diopters ($RD_{low/high}$) raised muskuloskeletal activation ($logEMG_{task}$) in only the binocular minus lens condition ($p<0.05$). See Table 1.

Table 1. Model Summary[1]

Viewing condition	Independent variable	Slope (β)	p-value	Goodness of Fit (QIC)
Lens blur (-3.5 D)	$LogEMG_{rest}$	0.505	<0.001	
	Time	0.026	0.001	
	$RD_{Low/High}$	0.187	0.016	
				64.5
Neutral reference (±0 D)	$LogEMG_{rest}$	0.478	<0.001	
	Time	0.027	0.001	
				76.4

[1]Dependent variable: $logEMG_{task}$.

4 Discussion

There were no trends in the data indicating that EMG activity increased during rest period (baseline). During the rest period subjects sat in the same chair, assumed the same posture, and were not allowed to move during 3 minutes. Since EMG (across min 1-3) was stable over time, biomechanical effects of the sitting posture on EMG_{task} may be ruled out.

The results from the present GEE analyses gave support for hypothesis one, which stated that EMG would increase over minute 1-7 due to the mental/physical task demands. Sympathetic arousal (e.g. caused by mental stress) can be ruled out as a cause behind the observed increase in trapezius muscle activity because no sign of this was apparent in the ECG recordings and analysis of heart-rate variability.

Hypothesis two, which stated that sustained periods of static accommodation/vergence load have a significant effect on muscle activity in the trapezius muscle, with more ciliary muscle load leading to more trapezius muscle EMG activity, was confirmed in the minus lens viewing condition. The neutral reference condition (±0 D) did not induce trapezius muscle EMG activation that was significantly associated with contraction of the ciliary muscle. In the minus lens viewing condition (-3.5 D) a statistically significant relationship between response diopters, and trapezius muscle EMG activation was found.

During the minus lens viewing condition accommodation/convergence was not optimally postured onto the target, resulting in blur and/or double vision in the retinal image. For those participants that compensated for the induced blur by increasing the ciliary muscle tonus and the dioptric power of the crystalline eye-lens, averaged trapezius muscle EMG activity was significantly larger in magnitude. When triggered by strenuous near work, central nervous system efferentation targeted to the oculomotor system may cross over to motor tracts and drive and posture the visual-musculoskeletal effectors in a synergistic fashion. The end result of this synergy may be "too much" gaze stabilization. Notably, oculomotor load of the type studied here may arise due to numerous other causes than by minus blur, e.g. be triggered by an uncorrected hyperopia, exophoria or general fatigue of eye-lens accommodation, etc.

The present results confirm and extend previous research [1, 2] and suggest that sustained eye-lens accommodation at near, during ergonomically unfavorable viewing conditions, may increase the risk for trapezius muscle myalgia.

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