Journal of Electromyography and Kinesiology 28 (2016) 193–198

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Ciliary muscle contraction force and trapezius muscle activity during manual tracking of a moving visual target

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ARTICLE INFO

Article history:
Received 3 June 2015
Received in revised form 17 November 2015
Accepted 19 November 2015

Keywords:
Ciliary muscle
Trapezius muscle
Near work

ABSTRACT

Previous studies have shown an association of visual demands during near work and increased activity of the trapezius muscle. Those studies were conducted under stationary postural conditions with fixed gaze and artificial visual load. The present study investigated the relationship between ciliary muscle contraction force and trapezius muscle activity across individuals during performance of a natural dynamic motor task under free gaze conditions. Participants ($N = 11$) tracked a moving visual target with a digital pen on a computer screen. Tracking performance, eye refraction and trapezius muscle activity were continuously measured. Ciliary muscle contraction force was computed from eye accommodative response. There was a significant Pearson correlation between ciliary muscle contraction force and trapezius muscle activity on the tracking side (0.78, $p < 0.01$) and passive side (0.64, $p < 0.05$). The study supports the hypothesis that high visual demands, leading to an increased ciliary muscle contraction during continuous eye–hand coordination, may increase trapezius muscle tension and thus contribute to the development of musculoskeletal complaints in the neck–shoulder area. Further experimental studies are required to clarify whether the relationship is valid within each individual or may represent a general personal trait, when individuals with higher eye accommodative response tend to have higher trapezius muscle activity.

1. Introduction

According to a growing body of research, due to deficient optical/physiological aspects of the near work (e.g., poor lighting, incorrect optical correction, deficient workstation layout, etc.), prolonged visual load can cause not only eye symptoms, but may also give rise to a parallel increase in musculoskeletal load and symptoms in the neck/scapular area. These complaints may either be physiologically interrelated (Richter and Knez, 2007), or a result of either a change in posture due to eye fatigue (Mon-Williams et al., 1998) or non-optimal optical correction (Horgen et al., 2002). Alternatively, oculomotor fatigue may lead to a secondary change in innervations to the postural muscles in the neck/scapular area, resulting in discomfort in these areas (Richter et al., 2005, 2010). Symptoms related to eye strain have been shown to be associated with musculoskeletal symptoms in the neck and shoulder area (Rosenfield et al., 2012) and with computer work that puts high demands on the eye hand coordination (Toomingas et al., 2014).

Previous research has suggested that eye accommodation is integrated with functionality of the neck and shoulder muscles. Simons (1943) and Lie and Watten (1987) showed increased neck muscle activity as a function of visual demands during near work. However, the eye accommodation level was not continuously monitored in those studies. More recent studies, which objectively and continuously measured eye accommodation while measuring neck muscle activity at the same time, confirm the existence of an association between visual demands during near work and increased activity of the neck muscles, specifically the trapezius muscle (Richter et al., 2010, 2011; Zetterberg et al., 2013). These studies were conducted under stationary postural conditions with fixed gaze and with an artificially induced visual load (blur induced by lenses). In the studies by Richter et al. (2010, 2011), visual load was too high to be comparable to a typical work situation. In none of these studies were the participants given any manual task, which is usually included in a typical computer work situation.

It is currently unclear if the aforementioned association between accommodation/vergence demands and neck muscles activity, obtained during static gaze conditions (i.e., with the head

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http://dx.doi.org/10.1016/j.jelekin.2015.11.008
1050-6411/

and arms completely stationary and resting), would transfer to a more ecologically valid and dynamic work life situation. Answering this question would be occupationally highly relevant for the assessment of eye accommodation load as a possible risk factor for the development of chronic neck pain. Therefore, in the present study, we looked at the relationship between eye accommodative response and trapezius muscle activity under conditions that were ecological and relevant for working life, i.e., during performance of a natural dynamic motor task resembling computer work under free gaze conditions.

In previous studies (Richter et al., 2010, 2011; Zetterberg et al., 2013), the level of visual demands was optometrically measured by a photorefractor as eye lens refraction power (converted into dioptric force of the accommodation response), which is an indirect measure reflecting the force of contraction of the ciliary muscle. Fisher (1977), using enucleated eyes, performed direct measurements of ciliary muscle contraction force and the correspondingly produced eye lens refraction power, prompting him to suggest a computational formula that takes into account non-linear and age-dependent relationships between eye lens refraction and ciliary muscle contraction force. In the present study, we, too, employed indirect optometric measurements to collect data on eye lens refraction (i.e., eye accommodation), but for the data analysis, we used Fisher's formula (Fisher, 1977) to compute ciliary muscle contraction force so as to provide a more individualized (age-adjusted) and physiologically relevant parameter for the description of the relationship between two muscle effectors: ciliary muscle and trapezius muscle.

The aim of this study was to investigate the relationship between ciliary muscle contraction force and trapezius muscle activity across individuals in a situation representing an occupational setting. The main hypothesis of the study was that the increased contraction force of the ciliary muscle (higher accommodation response) is associated with higher trapezius muscle activity.

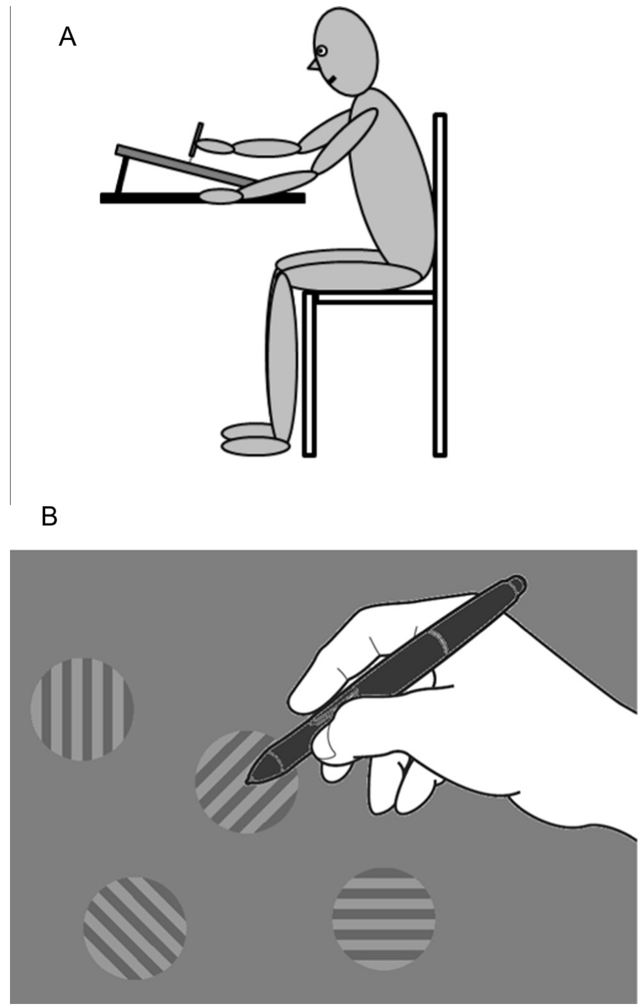

Fig. 1. (A) Experimental set-up. (B) Tracking of the visual target. The pen tip is placed in the middle of the tracking target. Other three circles are non-target objects.

2. Methods

2.1. Participants

Twelve right-handed individuals, age 23 ± 3 years (Mean ± SD), five men and seven women, with normal or corrected to normal vision and without musculoskeletal complaints in the neck, shoulders, arms or hands, participated in the study. The study conformed to the standards set by the Declaration of Helsinki. The Regional Ethics Review Board approved the study. All participants gave their written informed consent before participation. One male participant exhibiting outlier responses due to technical issues was excluded from data analysis, thus leaving $N = 11$ participants in the study.

2.2. Testing procedure

Participants sat at a table, with their head resting on a support for the chin and forehead to restrict head movements. A computer screen was placed on the table in front of the participants in a landscape orientation and with the elevation of 22° relative to the table surface (Fig. 1a). The screen was a Wacom PL2200 interactive display (DTU-2231, Wacom Ltd, Japan) with a screen size of 47.6 × 26.8 cm and a resolution of 1920 × 1080 pixels.

The participants' task was to use a hand-held digital pen to track a low contrast, slowly moving visual target inside the central screen area, which was 5 × 5 cm. The coordinates of the tip of the digital pen were continuously sampled at 133 Hz with a resolution of 0.01 mm. The duration of the tracking task was seven minutes. The eye–screen distance was constant at 40 cm (2.5 dioptres). The tracking target was a circle of 5 mm in diameter (0.7° visual angle), moving at the speed of 5 mm/s along a pseudo-random pre-computed unpredictable trajectory. The participants were instructed to track the target keeping the pen tip in the middle of the circle (Fig. 1b).

For optimal stimulation of accommodation, the spatial frequency of the circle's grey shading square-wave grating surface was set to 7 cycles/deg (Owens, 1980). The square-wave gratings of the tracking target were inclined at 45° clockwise from the vertical (Fig. 1b). Along with the tracking target, three other non-target circles with different inclinations of grating (vertical, 45° counter clockwise relative to the vertical and horizontal) were moving on the screen in the vicinity of the target circle and along pseudo-random pre-computed unpredictable trajectories (Fig. 1b). The movement speed of non-target circles varied, around 4.8 ± 3.2 mm/s (Mean ± SD). In the constant presence of the three non-target circles with different inclinations of grating, the participants had to continuously maintain a proper level of eye accommodation on the screen in order to be able to distinguish and track the target circle. In addition, a standardized task instruction emphasized active accommodation: look at the moving target and carefully track it with the pen at all times.

From continuously sampled coordinates of the pen tip and of the tracking target, we computed a measure of tracking