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Sounding Board

Neck pain brought into focus

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Abstract. A time honored dictum states that the eyes "lead the body", i.e. that the body typically adjust its position to compensate for an impoverished retinal image (e.g., as due to optical blur, and/or inappropriately sized visual target). But only moderate or low level of evidence exists in support of this view. Inconclusive evidence does not, however, equal negative evidence. The accommodation/vergence system does exhibit signs of overload in contemporary working life, including eye discomfort, transient myopia, altered pattern of eye-lens oscillations, and associated phoria. Accommodation/vergence overload, caused by non-ergonomic near work, may also emerge as quickly as within one regular workday. Long-term musculoskeletal consequences of high accommodation/vergence demands have nevertheless not yet been studied in any detail. A research agenda which aims to provide multi-scientific evidence for eye-neck/shoulder interactions with public health implications and which also, in addition, study the eye-neck/shoulder mechanisms and elucidates the operating characteristics, should consequently be highly warranted. This new knowledge would be useful for physiotherapists, ergonomists and opticians, who in their profession treat patients experiencing vision- and musculoskeletal disorders. If both visual and the musculoskeletal aspects are given full and equal weight in the design and evaluation of work places, it is predicted to lead to an improved quality of life for the individual worker, and an enhanced productivity for the employer.

Keywords: Accommodation, asthenopia, gaze stabilization, electromyography, computer work, visual ergonomics

1. Biologically plausible pathways with relevance for work related musculoskeletal disorders of the neck and upper extremity

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 these 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 large variety in symptoms points to several mechanisms that may act simultaneously or to different mechanisms which act for different risk factors [1]. The point of departure for the present sounding board 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.

Vision is one of the most important human senses. Our visual system has two distinct components: the optical system that alters light before it reaches the retina, and the neurological system (including both the retina and brain) that processes the information. Each of us confronts the visual world from a brain linked to what is "out there" by a few million fragile sensory nerve fibers. The visual system is sculptured by evolution. This implies that afferent nerve fibers are not high-fidelity recorders, but that they accentuate certain stimulus features and neglect others [2]. One consequence of this circumstance is that the visual system is not optimally adapted to our contemporary work life and sedentary life styles. Performance of many tasks in contemporary work life involves heavy reliance on high-quality visual input. The load on the visual system can be substantial and the visual conditions can be problematic, leading to decreased system performance. It can also decrease well-being and contribute to general health problems [3–8].

Modern work often requires people to view laptop and tablet computers, electronic books, smart phones and other electronic devices, either in the workplace, at home, or in the case of portable equipment, in any location. Some screen sizes necessitate very small text, viewed at a close distance, much different from older hard copy printed materials. Multiple work tasks are often executed simultaneously under these conditions. A recent estimate of internet usage indicates that 28.7% of the world's population currently uses computers and digital electronic devices for both vocational and non-vocational activities [9]. In North America and Europe internet usage covers almost 80% of the population. Conspicuously, many of these users of modern information technology, approximately 30–80%, occasionally report symptoms of fatigue, discomfort or pain from the eyes [8,10]. Apart from quality of life these symptoms carry considerable cost to society in terms of reduced productivity.

According to a growing body of research, an increase in visual load (augmented activity levels of eye-muscles) over time, due to deficient optical/physiological aspects of the near work (e.g., poor lighting, incorrect optical correction, uncorrected visual correction, deficient work station layout, insufficient rest periods, etc.), causes not only eye symptoms, but also gives rise to a parallel increase in musculoskeletal load and symptoms in the neck/scapular area [11]. These complaints may either be physiologically interrelated [12], or be a result of a change in posture e.g. triggered by eye-fatigue [13] or non-optimal spectacle correction [7]. 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 [14,15]. Information Technology (IT) workers with eye symptoms have been shown to have an elevated risk of having neck/scapular area symptoms [16].

Very few studies have focused on the association between oculomotor effort, eyestrain and neck and shoulder disorders in working life. Although the literature and common sense supports the notion that eyestrain and neck/shoulder symptoms are common among employees in modern offices, the two symptom categories are paradoxically analyzed in isolation within disparate disciplines of applied or clinical science. Accordingly, the evidence for a linkage between eyestrain and neck/shoulder complaints so far is underestimated and surprisingly limited in scope [17]. Even in laboratory experiments, the oculomotor and the musculoskeletal aspects of visual functioning have been addressed separately.

Accommodation and vergence mechanisms in the visual system in all likelihood form biologically plausible pathways 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 neck pain occurs. 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.

2. Accommodation/convergence functioning

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. Accommodation refers to the lenticular-based change in refractive state of the eye to attain and maintain a maximally high contrast foveal retinal image. There are four components that contribute to the overall accommodative response: these include blur, disparity, proximal and tonic accommodation [20]. 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.

It is possible that a neural command to sharply fixate a target at near such as an alphanumerical character could functionally impact on neck/scapular area muscles functioning by increasing the mechanical load and by reducing the load variation, in order to stabilize gaze. Comparatively little is known about this sort of stabilizing eye-neck muscle synergy. The erroneous view was often adopted that the focusing process of the eye was deterministically controlled by retinal contrast and/or other peripheral optical/physiological factors. As the science of photography was developed during the 19th century, the optical-geometrical way of looking at visual accommodation was accentuated by comparing the eye to a camera. To date almost all of our knowledge of visual stabilization comes from studies when visual stabilization is violated [18,19]. The action of the accommodation/vergence system has never been monitored simultaneously with musculoskeletal activity in the neck/shoulder area during naturalistic work conditions [11].

3. Gaze stabilization

The unrestrained head shows considerable motion during naturalistic viewing conditions, even when attempts are made to keep it as still as possible. Active image stabilization by neck/scapular area effectors is therefore necessary to minimize the occurrence of unwarranted extra foveal stimulation. In many animals, including human beings, the inner ear functions as the biological analogue of an accelerometer in camera image stabilization systems, to stabilize the image by moving the eyes. When rotation of the head is detected, an inhibitory signal is sent to the extraocular muscles on one side and an excitatory signal to the muscles on the other side. The result is a compensatory movement of the eyes. This is important because the eye-lens accommodative response degrades rapidly if the stimulus target is not projected directly into the fovea, the central portion of the retina where sensory photoreceptors responsible for high resolution processing of our visual surround is located.

4. Gaze stabilization during prolonged near work

Many laboratory studies have demonstrated temporary changes in oculomotor function, such as recession of the near point of accommodation and convergence, delayed rates of accommodation, shifts in accommodation towards the resting point, changes in muscle balance, and induced myopia after exaggerated near work [21–23]. During poor near work conditions, due to deficient optical/ physiological aspects of the near work, the optical axis of the eyes may momentarily diverge relative to the target of regard. Consequently, accommodation/convergence may no longer be optimally postured onto the target, resulting in blur and/or double vision in the retinal image. Under such adverse circumstances a compensatory response may be elicited by the central nervous system, with the goal of realigning the oculomotor response onto the target. 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 achieved may be "too much" gaze stabilization.

More knowledge about the mechanisms underlying eye-neck/scapular area interactions and gaze control during visually strenuous/fatiguing near work conditions with specific reference to occupational asthenopia and musculoskeletal disorders are highly warranted.

5. Mechanism(s) underlying gaze stabilization during sustained foveal fixation

The muscles which control convergence/divergence eye movements are skeletal. The ciliary muscle is a smooth muscles innervated primarily by the parasympathetic branch of the autonomic nervous system. The ciliary muscle is unique among all parasympathetically dominated smooth muscles in the body because it has many characteristics of fast striated muscles [24]. Recent histological observations indicate that the human ciliary muscle contains sensory nerve endings [24]. These nerve terminals have mechano – receptorial features with a morphology that seems to vary according to the receptors' location within the muscle. Collectively they are assumed to monitor stretch and tension, and thereby provide information about the contractual state of the ciliary muscle. These receptors could form the basis for a self – contained reflex arc which unites ciliary muscle activity and trapezius muscle activation. The presence of such a neural mechanism would facilitate fine control of focus and make the presumed gaze stabilization mechanisms less dependent upon voluntary effort. Such a proprioceptive afferent signal driving the muscles which stabilizes gaze would be proportional to the actual contraction of the ciliary muscle (i.e., giving rise to more trapezius muscle acticivity from more ciliary muscle action).

Another source of an eye-neck/scapular area interaction may arise from the efference copy of the motor command to the ciliary muscle. In contrast to proprioception, this type of extra- retinal information is believed to have little time -lag and the efferent signal copy is assumed to reach the brain which in turn executes a gaze stabilization command to the trapezius muscle within the same narrow time frame as the original signal reaches the neuromuscular junction. Elsewhere, other mechanisms which also may link eye-neck/shoulder muscle activity with one another have been described [11].

Regardless of the specific mechanisms, it is thought that sustained periods of oculomotor load significantly influences the postures and muscle activity in the neck/scapular region, with more oculomotor load leading to more musculoskeletal activity.

6. Is eye muscle fatigue a cause for trapezius muscle activation?

While skeletal muscle fatigue is defined as a progressive decline in maximum voluntary force produced by a muscle or muscle group [25] comparatively less is known about visual fatigue. Fatigue in the muskuloskeletal sense refers to a difficulty in initiating or sustaining voluntary activities, such as sustained maximal voluntary hand force. Traditionally this type of fatigue is classified as physical or mental. Physical fatigue, in turn, can be classified as peripheral or central [25]. It was recently suggested that the extraocular and ciliary muscles of the eye are, unlike skeletal muscles, resistant to fatigue [26,27]. Hence, the performance decrease associated with repeated eye accommodation from strenuous near work may not actually be muscle fatigue. Comparison of multi-unit smooth muscle contraction with skeletal muscle contraction pinpoint several basic differences which may account for this outcome. Most skeletal muscles contract rapidly whereas smooth muscles contract slowly and with prolonged tonic force, often lasting hours [28]. Only 1/10 to 1/300 as much energy is required to sustain the same tension of contraction in smooth muscles as in skeletal muscles [28]. This economy of energy utilization by smooth muscles is important to the overall energy economy of the body because the smooth muscles maintain tonic muscle contraction throughout the day. Hence, once the ciliary muscle has developed full contraction (during nearwork), the degree of activation of the muscle probably is reduced to far less than the initial level and yet the muscle still maintains its full strength of contraction. The energy consumed to maintain contraction may be minimal [28].

The functionality of smooth muscle functioning appears to prevent mechanical fatigue to occur. This poses the question if ciliary muscle functioning *per se* ever is compromised during strenuous near work, and if so in what way? One possibility is that the performance decrease frequently reported in the literature is caused by other mechanism, such as e.g. mental fatigue. However, results from an in vitro model appear to be at odds with this explanation [29]. In this experiment ciliary muscle removed from rabbit eyeballs was stimulated with acethylcholine, resulting in contraction of the muscle. Repeated stimulations caused decreased contraction, which was attributed to fatiguing of ciliary muscle (due to down regulation of acetylcholine receptor or downstream signaling of molecules).

Another shortcoming with the eye-lens accommodation literature of relevance to this discussion is that only indirect measures of ciliary muscle function have been obtained in the majority of the reported studies. This may be a pragmatic choice since there have been very few other options (cf. 30), but the choice of methodology nevertheless has implications e.g. potential asthenopia inducing changes in ciliary muscle activity, during or after sustained and strenuous near work (e.g. in post task measurements), may largely be unnoticed. In presbyopic subjects it is not possible to obtain measures of ciliary muscle activity with conventional measurement techniques because ordinary refractometers rely on indirect measures of ciliary muscle function which necessitate full integrity of the crystalline lens. More specifically, if the central nervous system elicits extra efferentation to the ciliary muscle in order to counteract pre-motor mental fatigue and/or local fatigue in the ciliary muscle, then the retinal image will not be compromised and conventional optometric measurements will not detect an aberrant accommodative response. Nevertheless, an imbalance (incongruent activation) may arise within the accommodation/vergence system and this could induce symptoms and/or neck/scapular area activity.

One controversy impeding progress in this context relates to the current lack understanding of resistance to fatigue development in the eye-muscles. Hence, identifying a reliable set of dependent measures of oculomotor fatigue is an important objective for future research.

7. Is imbalance in binocular vision a trigger for trapezius muscle activation?

In contrast to the models described previously, which attribute an increase in musculoskeletal load and symptoms in the neck/scapular area to mechanical use/overuse of accommodation or convergence, a mismatch between accommodation and convergence may also be the cause. It can be postulated that working with modern IT-technology introduces a combination of demands which generates a physiological stress response. The effect of this autonomic nervous system activity is to generate a discrepancy between the accommodation and convergence system. Sympathetic nervous system has been proposed as the mediating mechanism underlying this effector system mismatch [21]. Heightened attention and mental effort has been reported to produce a reduction in the magnitude of the accommodative response, mediated by enhanced sympathetic innervations to the ciliary muscle [20,21]. To maintain conjugate focus, a parasympathetic induced increase in the innervation must occur to override the sympathetically driven negative shift that accompanies increased mental effort. Increased parasympathetic innervation to achieve conjugate focus in turn generates increased accommodative-convergence, and hence convergence tends to be closer than accommodation. The effort directed towards resolution of the mismatch between accommodation and convergence may lead to an increase in musculoskeletal load and symptoms in the neck/scapular area. Notably, an effector mismatch may also arise due to numerous other causes, e.g. be triggered by an uncorrected hyperopia, exophoria or general fatigue of eye-lens accommodation.

8. Conclusions

The relationship between the accommodation/vergence system and the musculoskeletal system can in all likelihood not be considered a simple one-way causal inference. Dynamic models of visual-musculoskeletal interactions are more reasonable from a functional perspective and offer a richer theoretical framework. The adverse influence on the musculoskeletal system, caused by the visual system, may be routed back to the point of origin. Neck muscle activation, caused by postural changes in response to visual stress is known to influence aspects of eye-lens accommodation, which opens the possibility for dysfunctional cross-talk between the two systems. Much is still unknown about the complex machinery behind these visuomotor interactions.

Although a close functional relationship between oculomotor load and activation of the neck and scapular muscles does seem realistic, there is little formal research reporting the mechanism(s) coupling the two systems to one another. Considering the scant knowledge of control mechanisms of ocular accommodation and their neglected role as a putative causal factor in neck/shoulder problems, applied research methods, clinical procedures and experimental and neuroergonomic techniques should be developed for studying the impact of deficient visual ergonomics on musculoskeletal functioning and health (e.g. motor variation, muscle activation levels, pain and discomfort, etc.) and *vice versa*. A concerted research agenda involving applied and basic science, covering these two research topics, is likely to provide a wealth of new data on the interconnectedness between the eye-neck/scapular area muscle effectors. Research activity originating from such a multi-scientific realm of science is highly warranted to resolve the research questions formulated in this paper and also to formulate entirely new research questions. This new knowledge would be useful for physiotherapists, ergonomists and opticians, who in their profession treat patients experiencing vision- and musculoskeletal disorders. For example, it may be possible to prevent neck/scapular disorders and eye discomfort by appropriate visual ergonomic interventions. Hence, the results from such research programs may influence preventive measures in the management of work related problems. This research also has broader public health implications as it could make a valuable contribution to the knowledge base required for the management of work related discomfort. The eyes steer the body!

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