

The effect of short time computer work on muscle oxygenation in presence of delayed onset muscle soreness

Samani, Afshin; Larsen, Ryan Godsk

Published in:

Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018) - Volume III

DOI (link to publication from Publisher):

[10.1007/978-3-319-96083-8_5](https://doi.org/10.1007/978-3-319-96083-8_5)

Creative Commons License

CC BY 4.0

Publication date:

2019

Document Version

Accepted author manuscript, peer reviewed version

[Link to publication from Aalborg University](#)

Citation for published version (APA):

Samani, A., & Larsen, R. G. (2019). The effect of short time computer work on muscle oxygenation in presence of delayed onset muscle soreness. In S. Bagnara, R. Tartaglia, S. Albolino, T. Alexander, & Y. Fujita (Eds.), *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018) - Volume III: Volume III: Musculoskeletal Disorders* (Vol. III, pp. 22-31). Springer. https://doi.org/10.1007/978-3-319-96083-8_5

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal -

Take down policy

If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.

The effect of short time computer work on muscle oxygenation in presence of delayed onset muscle soreness

Afshin Samani¹[0000-0001-6119-8231] and Ryan Godsk Larsen¹[0000-0002-4622-1453]

¹ Sport Sciences, Dept. of Health Science and Technology, Aalborg University, Aalborg, Denmark
afsamani@hst.aau.dk

Abstract. We aimed at investigating the effect of a short time low load repetitive task on the local muscle oxygenation kinetics in presence of delayed onset muscle soreness. Computer work was investigated as a model of low load repetitive task. Nine healthy male subjects participated in an experimental protocol consisting of a rest period and two blocks, each including two maximum voluntary contractions (MVC) of isometric bilateral shoulder elevation and a computer work session with 2 or 5 min duration between the MVCs in each block. Then a set of unaccustomed eccentric exercise (ECC) of shoulder elevation was implemented to induce delayed onset muscle soreness (DOMS) in the trapezius muscle. Identical experimental blocks were performed immediately and 24h after ECC. Local tissue saturation index (TSI) was continuously recorded over upper trapezius throughout the experiment. TSI parameters such as mean TSI at rest, during computer work as well as TSI drop, recovery and their descending and ascending slopes were computed following the MVCs. TSI drop and recovery and their corresponding descending and ascending slopes were reduced immediately after ECC ($p < 0.05$). The computer work caused an increase in TSI at rest prior to the MVCs ($p < 0.05$) and elevated oxygen consumption ($p < 0.05$). The observed changes in oxygenation kinetics seemed to appear after a strenuous exercise and they do not seem to be affected by the presence of DOMS. However, computer work as a model of low load repetitive task caused increased oxygen consumption in a following bout of muscle contraction.

Keywords: Computer work, musculoskeletal disorders, near infrared spectroscopy.

1 Introduction

Musculoskeletal disorders (MSD) are a major global health problem and are known to be multifactorial phenomena [1]. Our understanding of mechanisms underlying development of MSD particularly in jobs with low workload intensity with repetitive patterns, such as computer work is limited [2]. Repetitive low load muscular activity may result in alter blood supply and muscle oxidative metabolism [3].

Near infrared spectroscopy (NIRS) is a non-invasive technique which enables the investigation of muscle oxidative metabolism locally [4], and thus provides a tool to investigate the link between the disturbance of muscle tissue oxygenation and the

development of MSD. Notably, contrasting results have been reported when comparing muscle oxygenation between healthy subjects and patients with MSD. In healthy adults, a decrease in muscle oxygenation has been reported in forearm muscles during isometric submaximal contractions [5] and in trapezius during a repetitive task [6] and load bearing [7]. In contrast, studies in MSD patients have found no changes in oxygenation of trapezius and wrist extensor muscles during low load repetitive tasks and submaximal isometric contractions [8, 9]. Such discrepancies may be due to a bias in patient selection, differences in experimental setup, choice of NIRS variables and body regions [10].

As an endogenous muscle pain model, delayed onset muscle soreness (DOMS) has been widely used to mimic clinical musculoskeletal pain [11]. Thus, investigating the disturbances in muscle oxygenation in presence of DOMS may improve our understanding of the underlying mechanism contributing to development of pain. The literature regarding the effect of DOMS on oxygenation kinetics is equivocal [12, 13]. Particularly, our knowledge about the effect of DOMS on the kinetics of oxygenation in upper extremity muscles during low load repetitive work with relatively high precision demand such as computer work is lacking.

Prolonged duration of computer work has been suggested as a risk factor for development of MSD in the neck and shoulder area [14]. Additionally, sustained activity of trapezius muscle over 4 min periods in half of a working day has been found to be associated with the development of neck and shoulder pain [15]. Therefore, it is interesting to investigate the short time effects of computer work on muscle oxygenation below and above the suggested time threshold (4 min) and its interaction with the presence of DOMS. Due to structural damage and edema in eccentrically exercised muscle tissue [16], we hypothesized that DOMS would slow the kinetics of muscle oxygenation. Additionally, we hypothesized that the computer work over 4 min would intensify the effects of DOMS.

2 Materials and methods

2.1 Subjects

Nine right-handed recreationally active males (24.2 (2.0) years; 181 (9) cm; Weight 75 (6) kg), with no history of neck- and shoulder disorders, volunteered to participate in the study. All subjects abstained from strenuous exercise three days prior to and during the trials. Informed written consent was obtained from each participant, prior to initiating the experiment and conducted in accordance with the Declaration of Helsinki. The study was approved by the local ethics committee of Northern Denmark Region (N-20120036).

2.2 Experimental procedure

The study was performed over two consecutive days. Identical procedures were performed at three stages, i.e., before, immediately after and 24 h after a standardized eccentric exercise (ECC; described below). The procedures consisted of i) 2 min instructed rest where the subjects sat comfortably on a chair with their hands on their

lap, feet on the ground, looking straight ahead, ii) a 5 sec maximum voluntary isometric contraction (MVC) of the trapezius muscle (MVC Pre), iii) either a 2 or 5 min standardized computer mouse work session, iv) right after step iii, step ii was repeated (MVC Post), v) after at least 5 min rest, steps ii, iii and iv were repeated but with a different duration of standardized computer work session performed in step ii (the order of computer work duration was randomized across subjects but kept identical across the experimental stages for each subject). MVC trials were added to the protocol to increase the intramuscular pressure and disturb tissue perfusion such that the contraction-induced response of the vascular system could be investigated [17].

Maximum voluntary contractions. The subject gripped both sides of the seat pan while sitting on a comfortable chair, the elbows were fully extended, and the shoulders were in neutral position. A handheld dynamometer (Vernier, HD-BTA, Beaverton, OR) was placed under the subject grip to the seat pan to measure the exerted force during the MVC trial. Visual feedback of the exerted force and verbal encouragement were provided to the subjects.

Eccentric exercise. The subjects performed the ECC for 30 min in a shoulder dynamometer [18]. The exercise intensity was set to 120 % MVC measured under the shoulder dynamometer before the ECC trial started. The ECC consisted of 5 bouts of 10 repetitions (3 min of continuous activity), separated by a 3 min of rest. During each repetition, participants had to counteract the dynamometer vertical downward force as much and for as long as possible along the previously defined range of shoulder elevation [19].

Computer work sessions. The computer work-station was adapted individually according to guidelines (e.g. seat and desk height, full arm support) [20]. The task was composed of a cyclic mouse clicking on 6 markers to draw a graph. The time allowed for drawing a graph was 8 seconds and this procedure repeated with a randomly generated graph each time [19]. Before starting the preparation of the experimental setup and data recordings, the subject was familiarized with the experimental setup and the computer work.

2.3 Data recordings

Sensory motor assessments. The subjects were asked to score the level of the perceived pain in the shoulder area on a visual analog scale (VAS) prior to all the three stages (i.e. before, immediately after and 24h after the ECC). VAS was constructed on a scale from 0 'no pain' to 10 'worst imaginable pain'. Maximum force produced was measured by the handheld dynamometer during the MVC trials. The subjects' performance during computer work was evaluated by multiplying the average rate of graph drawings in the allocated time (i.e., 8 s) and the ratio of correct clicks to total number of clicks (higher number reflecting better performance).

Near infrared spectroscopy. Local tissue oxygen saturation in the trapezius muscle was monitored using near-infrared spectroscopy (NIRS) with a continuous wave technique (Oxymon Mk III, Artinis Medical Systems BV, Netherlands). The NIRS probe setup consisted of one receiver and three transmitters placed in a row with 3.5 cm the mean of inter-optode distances. The transmitter optode transmits NIRS beams at 860 nm and 765 nm which are mostly sensitive to oxy- and de- oxyhemoglobin (O₂Hb and HHb), respectively [21]. The tissue saturation index (TSI) (%) was calculated as the ratio of O₂Hb to O₂Hb + HHb. The O₂Hb, HHb and TSI values have been shown to be valid estimators of changes in tissue deoxygenation status representing regional imbalances between O₂ delivery and O₂ utilization in the tissue under the probe [22].

Before initiating the trials, the NIRS apparatus was calibrated and the TSI probe was placed over the descending part of the trapezius muscle centered on the lateral third of distance between 7th cervical vertebrae and the acromion. A wax marker was used to ensure an identical placement of the probe across the experiment stages. The TSI was continuously measured in all the aforementioned experimental steps from i through v. Prior to mounting the NIRS measurement system, ultrasound imaging (GE, Logiq S7 Expert, BCF Technology) was used to obtain an estimate of subcutaneous fat and muscle thickness at the site of NIRS measurement.

2.4 Data analysis

From the TSI signal, we chose a 65 second window starting from 10 s before the onset of MVC trial. The choice of the window length was based on previous results [23] showing an approximately 30% drop in TSI with an approximately 0.5 % per second recovery rate in tissue oxygenation of trapezius following a 70% MVC. The lowest point of the TSI in this time window was determined and the signal in the window was divided into a descending and an ascending part. The descending part of the window was fitted to a trapezoidal shape function starting with a steady level followed by a linear decay. A non-linear least square routine was applied to derive an optimal level and descending slope for the trapezoidal function [24]. A similar procedure was performed to derive the level and ascending slope of the TSI signal. The cross-correlation coefficient (CC) between fitted trapezoidal function and the experimental values was calculated and if the CC was below 0.75, that window of TSI signals was removed from the rest of the analysis (two trials from one subject and one trial from three subjects). The fitting quality was also visually inspected. The initial steady level of TSI, the amount of TSI drop and recovery from the steady levels to the corresponding value of TSI at the lowest point and the slope of the drop and recovery were calculated. TSI descending and ascending slopes would reflect the rate of oxygen usage and recovery of oxygen saturation, respectively [12]. This procedure was performed for the MVC trial before the computer work (MVC pre) and after the computer work (MVC post) during all three stages of the experiment. The mean value of TSI was also computed during the instructed rest and during the computer work sessions.

2.5 Statistical analysis

A linear mixed model (LMM) was applied to the outcome measures, i.e., VAS, exerted force during the MVC trials, computer work performance, TSI level prior to the MVC trial, the TSI drop and recovery and their corresponding descending and ascending slopes and TSI mean during computer work and rest. The effect of delay onset muscle soreness and its interaction with the computer work on the outcomes were investigated and compared. Experimental stages (before, immediately after and 24h), computer work duration (2 min 5 min, rest (only for the TSI mean)), contraction order (MVC pre and MVC post) were introduced as fixed factors in the LMM. Additionally, a repeated factor associated with the introduced factors was added to the model. When a significant effect was observed, a Bonferroni adjustment was performed for a pairwise comparison. We reported an index of effect size Ω^2 which indicates the partial variance described by a factor with respect to the full LMM model [25]. In all tests, $P < 0.05$ was considered significant. Mean values (standard deviation) were reported

3 Results

3.1 Sensory motor assessments

Experimental stages had a significant effect on reported VAS ($F_{2,16}=9.7$, $p=0.002$, $\Omega^2=0.36$), MVC force ($F_{2,15.1}=10.4$, $p=0.001$, $\Omega^2=0.3$) and computer work performance ($F_{2,14.1}=26.7$, $p<0.001$, $\Omega^2=0.21$). VAS was greater 24 h after ECC compared with VAS before ECC. VAS increased from 0 (0) before, 1.1 (1.2) immediately after and 2.5 (2.2) 24 h after the ECC. For all MVC trials, the MVC force was greater 24h after ECC compared with the MVC immediately after ECC. Table 1 shows the obtained force level in MVC trials. Computer work performance score was lowest before ECC and greatest 24 h after the ECC. The performance score increased from 1.03 (0.18) before, 1.19 (0.14) immediately after and 1.26 (0.10) 24 h after the ECC.

3.2 The local muscle oxygenation

The thickness of subcutaneous fat and muscle tissue at the site of NIRS measurement were 4.6 (1.9) and 20.4 (3.4) mm, respectively. The contraction order ($F_{1,46.2}=78.6$, $p<0.001$, $\Omega^2=0.19$) had a significant effect on the TSI level prior to the MVC trials. The TSI level prior to the MVC after computer work was greater than TSI level prior to the MVC before computer work. Table 1 includes the mean and standard deviation of TSI parameters. The contraction order ($F_{1,50.2}=27.1$, $p<0.001$, $\Omega^2=0.09$) and the interaction of duration \times the experimental stages ($F_{2,24.4}=7.1$, $p=0.004$, $\Omega^2=0.12$) had significant effects on the TSI drop. The TSI drop during the MVC was greater after computer work compared with before computer work. With the 2 min computer work, the TSI drop was lower immediately after the ECC compared with the drop before and 24 h after the ECC. The experimental stages ($F_{2,41.5}=16.7$, $p<0.001$, $\Omega^2=0.15$) and the contraction order ($F_{2,45.7}=4.7$, $p=0.03$,

$\Omega^2=0.01$) had significant effects on the TSI recovery. The TSI recovery was lower immediately after the ECC compared with before and 24 h after the ECC. The recovery was greater before the computer work compared with the recovery after the computer work.

Table 1. The mean and standard deviation of exerted force during maximum voluntary contractions (MVC) and derived parameters from the tissue saturation index (TSI). * and \$ indicate significant difference between the experimental stage immediately after the eccentric exercise (ECC) on the one hand and the experimental stage before and 24 h after the ECC, respectively. # shows a significant difference between the experimental stage immediately after and 24 h after the ECC.

Outcomes	Experimental stages					
	Before		Immediately after		24 h after	
	Pre	Post	Pre	Post	Pre	Post
MVC force (N)	484 (168)	475 (163)	441 (142)	443 (154)	510 (154) #	521 (147) #
TSI level prior the MVC (%)	61.9 (8.2)	66.8 (8.9)	62.5 (11.3)	66.2 (10.3)	59.5 (7.0)	64.9 (5.9)
TSI drop (%)	23.7 (16.2)	24.5 (14.1)	17.1 (11.9)	22.5 (12.0)	23.3 (15.5)	25.0 (15.9)
TSI recovery (%)	21.6 (15.2)	17.5 (12.1)	13.3 (10.6) *\$	12.6 (9.8) *\$	21.1 (15.3)	18.9 (14.7)
Descending slope (%/s)	3.3 (3.0)	3.2 (2.6)	2.5 (2.5) *\$	2.8 (2.3) *\$	3.3 (2.6)	3.8 (2.9)
Ascending slope (%/s)	1.8 (1.8)	1.8 (1.9)	1.5 (1.5) \$	1.7 (1.8) \$	2.2 (1.5)	1.9 (1.3)

The experimental stages ($F_{2,33.9}=9.7$, $p<0.001$, $\Omega^2=0.05$) and the contraction order ($F_{1,52.8}=6.7$, $p=0.01$, $\Omega^2=0.01$) had significant effects on the descending slope of TSI. The descending slope was smaller immediately after the ECC compared with before and 24 h after the ECC. The descending slope after the computer work was greater than the descending slope prior to the computer work. The experimental stages ($F_{2,21.6}=7.5$, $p=0.003$, $\Omega^2=0.02$) had a significant effect on the ascending slope of TSI. The ascending slope was smaller immediately after the ECC compared with 24 h after the ECC. TSI mean during computer work did not change significantly compared to the rest period. Table 2 shows the mean and standard deviation of TSI mean during the computer work sessions.

Table 2. The mean and standard deviation of the tissue saturation index (TSI) across subjects during the computer work sessions.

TSI mean (%)	Experimental stages		
	Before	Immediately after	24 h after

Rest	60.6 (6.7)	65.7 (11.5)	60.9 (8.3)
2 min	65.9 (7.9)	67.5 (9.8)	64.5 (5.7)
5 min	65.7 (11.5)	65.3 (9.5)	63.5 (6.0)

4 Discussion

The TSI drop and recovery and their corresponding descending and ascending slopes were reduced immediately after ECC. The reduced drop in TSI may partly be a consequence of a decrease in the exerted force during the MVC trials, while slower recovery of TSI suggests impaired re-oxygenation of the muscle tissue following ECC. The computer work caused an increase in TSI level prior to the MVC, most likely due to exercise induced hyperemia. The computer work also elevated oxygen consumption, reflected by the greater drop in TSI after computer work compared with the drop before computer work. The duration of computer work did not result in significant different TSI responses during and after the MVC, except that TSI drop was lower immediately after the ECC compared with 24 h after and before the ECC with 2 min computer work only.

The increased VAS 24 h after the ECC may indicate some typical structural changes in the muscle or connective tissue as similar levels of VAS have been reported by [26] using a very similar ECC protocol with somewhat lower exercise intensity compared to our protocol. Despite significant sensory-motor changes in presence of DOMS, previous studies, in line with our results, have also not found a significant change in the exerted force during MVC trials [27].

Our results are in accordance to [28] as no alteration in the NIRS parameters in presence of DOMS was observed. However, as opposed to Walsh et al. (2001) [28], who have investigated the effect of DOMS on muscle oxygenation in vastus lateralis, we focused our study on oxygenation kinetics in the trapezius muscle. It is expected that ECC may damage slow twitch muscle fibers to a lesser extent compared with fast twitch fibers [29] and type II fibers constitute the major part of vastus lateralis in males [30], whereas the trapezius has a larger proportion of type I fibers [31].

In this study, DOMS did not seem to have an effect on the TSI parameters at rest which might be due to a different acute immunological response to DOMS compared with the conditions of chronic MSD [16]. Ahmadi et al. (2008) [12] have reported TSI levels at rest and during isometric contractions of the knee extensors before and after exercise induced muscle damage. Similar to our findings, they have not reported any changes in TSI at rest across the experimental stages. However, in contrast to our study, they reported faster oxygenation kinetics in presence of DOMS. Apart from a different site of recording and constant level of force across the experimental stages (discussed below), the subjects in Ahmadi et al. (2008) [12] were relatively sedentary, and the ECC protocol may therefore have had a larger impact on the muscle tissue in their participants. Interestingly, the subjects in Walsh et al. (2001) [28] consisted of recreationally active individuals, similar to our subject group, and they reported no changes in TSI parameters in presence of DOMS.

The reduced drop and recovery in TSI and their corresponding slopes immediately after the ECC is partly explained by the reduced level of exerted force during MVC trials [24]. However, eccentric exercise has been suggested to impair oxygen extraction and reduce microvascular function [32], which may also contribute to altered kinetics of muscle oxygenation in our study. Ahmadi et al. (2008) [12] kept a constant submaximal force level across the experimental stages, which may affect the reliability of the NIRS parameters at lower relative force levels [23]. Particularly, the NIRS parameters have been recommended to be assessed at maximal force level in clinical applications [33]. Therefore, the MVC trials constitute a crucial part of the experimental design enabling the assessment of the effect of computer work on tissue oxygenation kinetics with and without presence of DOMS.

The TSI level prior to the MVC trials was greater after the computer work compared with TSI level prior to the MVC trials before the computer work. This is probably due to increased muscle perfusion which is low at rest but gradually increases with exercise intensity [34]. As the muscle contraction level during the computer work is quite low, below 10% of maximum capacity [35], the intramuscular pressure cannot disturb the blood flow [17]. However, the drop in TSI was greater after the computer work, suggesting that short term computer work elevates the oxygen consumption in the trapezius muscle during the MVC trials.

In contrast to our hypothesis the duration of computer work did not result in significant changes in the TSI parameter. However, TSI drop was lower immediately after the ECC compared with 24 h after and before the ECC only with 2 min computer work. This may suggest that the abovementioned increased oxygen consumption after computer work may be intensified with the accumulated effect of 5 min computer work.

The subjects' performance during computer work increased across the experimental stages, which may be due to a learning effect. However, in a similar experimental setup, the performance did not change significantly when comparing computer work performance under experimental pain condition and baseline on the same day [36]. Along the timeline of our experiment, the subjects may have been mentally motivated to supersede their previous performance.

We conclude that despite the lack of DOMS effect on the TSI parameters, short time low intensity repetitive work such as computer work can affect the kinetics of muscle tissue oxygenation. Notably, the changes in oxygenation kinetics appear immediately after ECC and not 24 h post-exercise. This may suggest that these changes are due to the exercise bout itself and not due to structural changes in muscle tissue after eccentric exercise. Further, studies are warranted to specifically investigate the interaction of DOMS and prolonged low load repetitive tasks.

References

1. Bernard, B. P. Musculoskeletal disorders and workplace factors. NIOSH Publication: Second Ed. US Department of Health and Human Services, Cincinnati, OH, 1:97-141 (1997).

2. Perrey, S., Thedon, T. and Bringard, A. Application of near-infrared spectroscopy in preventing work-related musculoskeletal disorders: Brief review. *Int. J. Ind. Ergonomics*, 40:180-184 (2010).
3. Visser, B. and van Dieën, J. H. Pathophysiology of upper extremity muscle disorders. *J Electromyogr Kinesiol*, 16:1-16 (2006).
4. Ferrari, M., Muthalib, M. and Quaresima, V. The use of near-infrared spectroscopy in understanding skeletal muscle physiology: recent developments. *Philos. Trans. A. Math. Phys. Eng. Sci.*, 369:4577-4590 Nov 28, (2011).
5. Brunnekreef, J. J., Oosterhof, J., Thijssen, D. H., Colier, W. N. and Van Uden, C. J. Fore-arm blood flow and oxygen consumption in patients with bilateral repetitive strain injury measured by near-infrared spectroscopy. *Clinical Physiology and Functional Imaging*, 26:178-184 (2006).
6. Sjøgaard, G., Rosendal, L., Kristiansen, J., Blangsted, A. K., Skotte, J., Larsson, B., Gerdle, B., Saltin, B. and Søgaard, K. Muscle oxygenation and glycolysis in females with trapezius myalgia during stress and repetitive work using microdialysis and NIRS. *Eur. J. Appl. Physiol.*, 108:657-669 (2010).
7. Mao, C. P., Macias, B. R. and Hargens, A. R. Shoulder skin and muscle hemodynamics during backpack carriage. *Appl. Ergon.*, 51:80-84 (2015).
8. Elcadi, G. H., Forsman, M., Aasa, U., Fahlstrom, M. and Crenshaw, A. G. Shoulder and forearm oxygenation and myoelectric activity in patients with work-related muscle pain and healthy subjects. *Eur. J. Appl. Physiol.*, 113:1103-1115 (2013).
9. Flodgren, G. M., Crenshaw, A. G., Hellstrom, F. and Fahlstrom, M. Combining microdialysis and near-infrared spectroscopy for studying effects of low-load repetitive work on the intramuscular chemistry in trapezius myalgia. *J. Biomed. Biotechnol.*, 2010:513803 (2010).
10. Elcadi, G. H., Forsman, M., Hallman, D. M., Aasa, U., Fahlstrom, M. and Crenshaw, A. G. Oxygenation and hemodynamics do not underlie early muscle fatigue for patients with work-related muscle pain. *PloS One*, 9:e95582 (2014).
11. Graven-Nielsen, T. and Arendt-Nielsen, L. Impact of clinical and experimental pain on muscle strength and activity. *Curr. Rheumatol. Rep.*, 10:475-481 Dec, (2008).
12. Ahmadi, S., Sinclair, P. J. and Davis, G. M. Muscle oxygenation after downhill walking-induced muscle damage. *Clinical Physiology and Functional Imaging*, 28:55-63 (2008).
13. Davies, R. C., Eston, R. G., Poole, D. C., Rowlands, A. V., DiMenna, F., Wilkerson, D. P., Twist, C. and Jones, A. M. Effect of eccentric exercise-induced muscle damage on the dynamics of muscle oxygenation and pulmonary oxygen uptake. *J. Appl. Physiol.* (1985), 105:1413-1421 Nov, (2008).
14. Blatter, B. and Bongers, P. Duration of computer use and mouse use in relation to musculoskeletal disorders of neck or upper limb. *Int. J. Ind. Ergonomics*, 30:295-306 (2002).
15. Hanvold, T. N., Wærsted, M., Mengshoel, A. M., Bjertness, E., Stigum, H., Twisk, J. and Veiersted, K. B. The effect of work-related sustained trapezius muscle activity on the development of neck and shoulder pain among young adults. *Scand. J. Work Environ. Health*, 39:390-400 (2013).
16. Smith, L. L. Acute inflammation: the underlying mechanism in delayed onset muscle soreness? *Med. Sci. Sports Exerc.*, 23:542-551 May, (1991).
17. de Ruitter, C. J., Goudsmit, J. F., Van Tricht, J. A. and de Haan, A. The isometric torque at which knee-extensor muscle reoxygenation stops. *Med. Sci. Sports Exerc.*, 39:443-453 Mar, (2007).
18. Madeleine, P., Nie, H. and Arendt-Nielsen, L. Dynamic shoulder dynamometry: a way to develop delay onset muscle soreness in shoulder muscles. *J. Biomech.*, 39:184-188 (2006).

19. Samani, A., Holtermann, A., Sogaard, K. and Madeleine, P. Effects of eccentric exercise on trapezius electromyography during computer work with active and passive pauses. *Clin. Biomech.*, 24:619-625 (2009).
20. Kroemer, K. H. E., Kroemer, H. B. and Kroemer-Elbert, K. E., *Ergonomics: How to Design for Ease and Efficiency*. New Jersey: Prentice-Hall, (2001).
21. Boushel, R. and Piantadosi, C. Near-infrared spectroscopy for monitoring muscle oxygenation. *Acta Physiol. Scand.*, 168:615-622 (2000).
22. Van Beekvelt, M. C., Colier, W. N., Wevers, R. A. and Van Engelen, B. G. Performance of near-infrared spectroscopy in measuring local O₂ consumption and blood flow in skeletal muscle. *J. Appl. Physiol.* (1985), 90:511-519Feb, (2001).
23. Crenshaw, A. G., Elcadi, G. H., Hellstrom, F. and Mathiassen, S. E. Reliability of near-infrared spectroscopy for measuring forearm and shoulder oxygenation in healthy males and females. *Eur. J. Appl. Physiol.*, 112:2703-2715 (2012).
24. Felici, F., Quaresima, V., Fattorini, L., Sbriccoli, P., Filligoi, G. C. and Ferrari, M. Biceps brachii myoelectric and oxygenation changes during static and sinusoidal isometric exercises. *Journal of Electromyography and Kinesiology*, 19:e1-e11 (2009).
25. Xu, R. Measuring explained variation in linear mixed effects models. *Stat. Med.*, 22:3527-3541 (2003).
26. Vangsgaard, S., Nørgaard, L. T., Flaskager, B. K., Sogaard, K., Taylor, J. L. and Madeleine, P. Eccentric exercise inhibits the H reflex in the middle part of the trapezius muscle. *Eur. J. Appl. Physiol.*, 113:77-87 (2013).
27. Binderup, A. T., Arendt-Nielsen, L. and Madeleine, P. Pressure pain threshold mapping of the trapezius muscle reveals heterogeneity in the distribution of muscular hyperalgesia after eccentric exercise. *European Journal of Pain*, 14:705-712 (2010).
28. Walsh, B., Tonkonogi, M., Malm, C., Ekblom, B. and Sahlin, K. Effect of eccentric exercise on muscle oxidative metabolism in humans. *Med. Sci. Sports Exerc.*, 33:436-441 (2001).
29. Lieber, R. and Friden, J. Selective damage of fast glycolytic muscle fibres with eccentric contraction of the rabbit tibialis anterior. *Acta Physiol. Scand.*, 133:587-588 (1988).
30. Staron, R. S., Hagerman, F. C., Hikida, R. S., Murray, T. F., Hostler, D. P., Crill, M. T., Ragg, K. E. and Toma, K. Fiber type composition of the vastus lateralis muscle of young men and women. *J. Histochem. Cytochem.*, 48:623-629May, (2000).
31. Lindman, R., Eriksson, A. and Thornell, L. E. Fiber type composition of the human male trapezius muscle: enzyme-histochemical characteristics. *Am. J. Anat.*, 189:236-244Nov, (1990).
32. Larsen, R. G., Hirata, R. P., Madzak, A., Frokjaer, J. B. and Graven-Nielsen, T. Eccentric exercise slows in vivo microvascular reactivity during brief contractions in human skeletal muscle. *J. Appl. Physiol.* (1985), 119:1272-1281Dec 1, (2015).
33. Muthalib, M., Millet, G. Y., Quaresima, V. and Nosaka, K. Reliability of near-infrared spectroscopy for measuring biceps brachii oxygenation during sustained and repeated isometric contractions. *J. Biomed. Opt.*, 15:017008 (2010).
34. Delp, M. and Laughlin, M. Regulation of skeletal muscle perfusion during exercise. *Acta Physiol. Scand.*, 162:411-419 (1998).
35. Jensen, C., Borg, V., Finsen, L., Hansen, K., Juul-Kristensen, B. and Christensen, H. Job demands, muscle activity and musculoskeletal symptoms in relation to work with the computer mouse. *Scand. J. Work Environ. Health*, 24:418-424 (1998).
36. Samani, A., Holtermann, A., Sogaard, K. and Madeleine, P. Experimental pain leads to reorganisation of trapezius electromyography during computer work with active and passive pauses. *Eur J Appl Physiol*, 106:857-66 (2009).