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Fatigue development in the finger flexor muscle differs between keyboard and mouse use

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Abstract

Purpose—The aim of the present study was to determine whether there were any physiological changes in the muscle as a result of intensive computer use.

Methods—Using a repeated measures experimental design, eighteen subjects participated in four different eight-hour conditions: a control (no exposure) condition and three exposure conditions comprised of 6 hours of computer use (keyboard, mouse, and combined keyboard and mouse use) followed by 2 hours of recovery. In each condition, using 2 Hz neuromuscular electrical stimulation, eight temporal measurements were collected to evaluate the fatigue state (twitch force, contraction time, and ½ relaxation time) of the right middle finger Flexor Digitorum Superficialis (FDS) muscle before, during, and after computer use.

Results—The results indicated that 6 hours of keyboard, mouse, and combined mouse and keyboard use all caused temporal fatigue-related changes in physiological state of the FDS muscle. Keyboard use resulted in muscle potentiation, which was characterized by approximately 30% increase in twitch force ($p < 0.0001$) and 3% decrease ($p = 0.04$) in twitch durations. Mouse use resulted in a combined state of potentiation and fatigue, which was characterized by an increase in twitch forces ($p = 0.002$) but a prolonging (11%) rather than a shortening of twitch durations ($p < 0.0001$).

Conclusions—When comparing mouse and keyboard use, the more substantial change in the physiological state of the muscle with mouse use (potentiation and fatigue compared to just potentiation with keyboard use) provides some physiological evidence which may explain why mouse use has a greater association with computer-related injuries.

Keywords

Electrical stimulation; muscle fatigue; computer use; musculoskeletal disorders

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Conflict of interest

No conflicts of interest, financial or otherwise, are declared by the authors

Introduction

Computer use has been associated with musculoskeletal disorders (MSDs) (Bergqvist et al. 1995; Gerr et al. 2002; Andersen et al. 2011). Amongst the possible risk factors, the rapid and repetitive finger movements during keyboard use and/or static muscle loading and postures during mouse use are thought to be major risk factors for computer-related MSDs (Jensen et al. 2002; Lin et al. 2004; Ijmker et al. 2007; Chang et al. 2009). Although exact underlying mechanisms are not fully understood, muscle fatigue may be a precursor and one of the underlying mechanisms contributing to the onset and development of computer-related MSDs (Armstrong et al. 1993; Rempel et al. 1992; Takala 2002; Dennerlein et al. 2003; Punnett and Wegman 2004; Thomsen et al. 2007).

Prolonged and repetitive low-intensity muscle contractions, which are typical characteristics of occupational computer use, have been associated with low frequency fatigue (LFF) (Westerblad et al. 2000; Dennerlein et al. 2003; Johnson et al. 2012); thus, LFF may play a role in the onset and development of musculoskeletal disorders in computer users (Westerblad et al. 2000; Dennerlein et al. 2003). LFF is a form of muscle fatigue where the force response of the muscle at low frequencies of electrical stimulation is disproportionally lower compared to the muscle's force response to high frequency stimulation (Edwards et al. 1977; Jones 1996; Enoka 2002; MacIntosh and Rassier 2002). During the onset and development of LFF, the physiological state of muscle goes through a series of changes (Alway et al. 1987; Rassier and Macintosh 2000). Volitional activation of the muscle can result in muscle potentiation which is characterized by increase in twitch force and decrease in contraction and ½ relaxation time (Vandervoort et al. 1983; Garner et al. 1989; Green and Jones 1989; Oleary et al. 1997; Gossen and Sale 2000; Hamada et al. 2000a; Hamada et al. 2000b; Miyamoto et al. 2011) (Fig. 1(b)). Muscle potentiation can result from both involuntary contractions (post-tetanic potentiation) in response to the muscle being subjected to electrical stimulation and voluntary contractions (post-activation potentiation) as a result of exposing the muscle to physical work (MacIntosh et al. 2006). Potentiation is thought to be due to either the phosphorylation of myosin regulatory light chains (Houston et al. 1985; Palmer and Moore 1989; Grange and Houston 1991; Grange et al. 1993), which increases the sensitivity of myosin heads to Ca^{2+} (Metzger et al. 1989; Sweeney and Stull 1990; Fowles and Green 2003), or the increased cytosolic Ca^{2+} concentration which facilitates the binding between the actin and myosin contractile proteins (Allen et al. 1989; Green and Jones 1989). These potentiation-mediated mechanisms are thought to delay the onset and development of muscle fatigue. Because of the protective effects of potentiation combatting the onset and development of muscle fatigue, if the duration of the exercise is short and/or its intensity is low, the muscle will end up in a state of potentiation (Fig. 1(b), increased force output and a shortened contraction duration) rather than a state of classical muscle fatigue (Fig. 1(e), decreased force output and a lengthened contraction duration).

If the exercise lasts long enough or requires a moderate amount of work, potentiation and fatigue can coexist (Vandervoort et al. 1983; Rankin et al. 1988; Grange and Houston 1991; Rassier and Macintosh 2000; Fowles and Green 2003). Compared to a pure state of potentiation (Fig. 1(b)), a combined state of potentiation and fatigue can be characterized with elevated twitch force (potentiated) and longer contraction time (fatigued) (Fig. 1(c)) or

with twitch force below the pre-fatigue state (fatigued) and decreased contraction time (Fig. 1(d)). Eventually, if the exercise is intense and long enough, muscle fatigue will overcome the potentiation and the muscle will enter the classical state of fatigue where the twitch forces will drop and the contraction durations lengthen relative to the pre-exercise, fresh muscle (Fig. 1(e)). This increase in contraction duration is the result of the lengthening of ½ relaxation times, which is one of the common observations in fatigue studies (MacIntosh et al. 2006). Previous studies involving human subjects have shown that muscle potentiation depends on both the intensity and the duration of the muscle contraction (Green and Jones 1989; Fowles and Green 2003). Potentiation has been shown to last 3 to 5 minutes after short to moderate duration, higher intensity (30 – 100 %MVC: Maximum Voluntary Contraction) exercises (Green and Jones 1989; Fowles and Green 2003), whereas potentiation has been shown to last longer (up to an hour) after longer duration, lower intensity (15 %MVC) exercise (Chang et al. 2009). Depending on the type of fatiguing exercise, a muscle does not necessarily have to go through all the five stages shown in Figure 1, but rather will go through some combination of stages (b), (c), (d) and (e). Each stage indicates a progression in the severity of the fatigue.

Different physical demands will lead to different physiological changes within the muscle and different states of muscle fatigue. Keyboard use is associated with highly repetitive finger movements whereas mouse use is more static in nature. These different muscle loading patterns have been used to explain why there are stronger injury associations between mouse use and MSDs when compared to keyboard use (Ijmker et al. 2007). Ijmker et al. (2007) showed that mouse use was more strongly and consistently associated with upper extremity musculoskeletal symptoms (higher risk estimates: odds ratio) as compared to keyboard use. The computer use has been more strongly associated with musculoskeletal symptoms in hand/arm regions than the symptoms in neck/shoulder (Ijmker et al. 2007; Gerr et al. 2004; Gerr et al. 2006). However, there has been a lack of physiological and/or clinical evidence to explain the different MSD associations between keyboard and mouse use; hence, the association between computer use and MSDs has long been debated (Waersted et al. 2010).

Therefore, this study tested the hypothesis that the computer use could cause temporal changes in muscle twitch force, twitch contraction time, and ½ relaxation time. In addition, we also hypothesized that there will be temporal differences in the muscle twitch parameters between the keyboard use and mouse use. If there are temporal differences in the way the muscle fatigues, the present study may provide some physiological evidence to help explain the different MSD associations between keyboard and mouse.

Methods

Subjects

Through e-mail solicitations, a total of 18 subjects including 9 males and 9 females were recruited to participate in this experiment. Since the computer using population is comprised of both male and female computer users, gender was balanced to minimize potential bias due to gender distribution. All the participants were right-handed touch-typists without a history of upper extremity MSDs. Their average typing speed was 60.3 (SD 13.2) words

per minute (WPM), ranging from 42 to 85 WPM. Their average age was 24.9 (SD 4.9) years old, ranging from 21 to 34 years old. The experimental protocol was approved by the University's Human Subject Committee, and all subjects provided the written informed consent prior to their participation in the study.

Experiment protocol

Using a repeated measures design, all subjects participated in five days of experimentation with one orientation day and four experimental days (Fig. 2). Between the experimental days, a minimum of 24 hours was allocated to minimize any residual fatigue effects from the prior experimental day. The four, eight-hour experimental days consisted of one control day when no work was performed and three exposure days comprising 6 hours of computer use (keyboard use, mouse use, and a combined activity consisting of 25% of keyboard and 75% mouse use) followed by 2 hours of recovery. There were 15-minute breaks in the morning and afternoon and a 30-minute lunch break in the middle of the day. The order of the four conditions was randomized.

As shown in Fig. 2, eight measurements were taken to evaluate the physiological state of the muscle. During each of those measurements, subjects were first asked to subjectively rate their muscle fatigue in the right hand, wrist, forearm, shoulder and neck using Borg CR-10 scales (McLoone et al. 2009; Borg 1982). The questionnaires were programed by LabVIEW software (Version 2009; National Instruments; Austin, TX, USA) to automate the recording of the subjective measures. Then, to objectively measure muscle fatigue, subjects received 2-Hz electrical stimulation to the right middle finger Flexor Digitorum Superficialis (FDS) muscle.

Repetitive and static movements during keyboard and mouse use are mainly driven by extrinsic finger muscles on the forearm. Thus, extrinsic forearm muscle was chosen for electrical stimulation. Due to its accessibility (superficial location) and primary role with computer use, the FDS muscle was evaluated since this muscle has been extensively studied in the previous physiological studies for computer-related MSDs and other muscle fatigue studies (Rempel et al. 1997; Dennerlein et al. 1998, 1999; Chang et al. 2009). In addition, the study of the extrinsic finger flexor muscles is supported by systematic reviews (Ijmker et al. 2007; Andersen et al. 2011) and epidemiological studies (Gerr et al. 2004; Gerr et al 2004) which have shown that computer use is associated with musculoskeletal symptoms in the hand and arm regions.

Low frequency electrical stimulation (Chang et al. 2009; Bennie et al. 2002; Adamo et al. 2009; Adamo et al. 2002; Thomsen et al. 2007; Johnson et al. 2012) was used to measure muscle fatigue in FDS muscle at the beginning of the experiment, during the 6-hour exposure period, and during 2 hours of recovery. As shown in Fig. 3, muscle twitches were evoked at 2 Hz using a S48 stimulator, a SIU5 stimulus isolation unit and CCU-1 constant current unit (Grass Instruments, W. Warwick, RI, USA). During the electrical stimulation, twitch forces were recorded at the rate of 5000 Hz using a force transducer (Greenleaf Medical Pinch Meter, Palo Alto, CA, USA) connected to a National Instruments data acquisition device (NI USB-6259 BNC; National Instruments Corporation; Austin; Texas). From the twitch forces collected, contraction times, ½ relaxation times, and total

twitch durations (contraction + ½ relaxation time) were calculated in real time using a LabVIEW program (Ver. 2009; National Instruments; Austin, TX, USA). As shown in figure 3, contraction time was the duration between the baseline and the peak twitch force; ½ relaxation time was the duration between the peak twitch force and the half of the peak. The force transducer has a 3% of full-scale accuracy and bandwidth of 1,000 Hz (Smutz et al. 1994; Dennerlein et al. 1999; Chang et al. 2009; Johnson et al. 2012).

On the orientation day prior to the four experimental days, the optimal location for administering electrical stimulation to the right middle finger FDS muscle was identified by moving two 2-milimeter diameter Ag-AgCl flat tip probes (Model: E208; In Vivo Metric, Healdsburg, CA, USA), with 20-mm center-to-center probe spacing, over the muscle belly of FDS until the muscle's twitch force response reached a maximum with minimal muscle recruitment from the adjacent fingers. Although the right index finger is the predominant finger used during regular mouse operations, the right middle finger was chosen to activate the mouse button and be stimulated because the index finger's FDS muscle is too deep to be stimulated using superficial electrical stimulation of the muscle. The middle finger FDS muscle was thought to be a reasonable surrogate to the index finger muscle, given that the middle finger has similar strength to the index finger (Martin et al. 1996; Radwin and Jeng 1997) and is also regularly used for both typing and mouse use (the right mouse button).

Once the optimal electrode sites for the right middle finger FDS muscle were identified, the subject's maximum tolerable stimulation intensity was determined by gradually increasing the current intensity until the level of subject's pain reached at six on a zero to ten pain scale (Hanchard et al. 1998). Since we could not stimulate the subject's muscle supramaximally, the goal was to stimulate their muscle with the greatest amount of current intensity that they were willing to tolerate. This maximum tolerable current intensity was used on all subsequent experimental days. The stimulation duration was 100 μs and the current ranged from 10 to 30 milliamps (Fig. 3). For consistent electrical stimulation results across the four experimental days, the skin over the stimulation sites was marked with *Hena* ink. The Henna ink markings lasted up to 14 days and were reapplied as needed during the experiment.

On the four experimental days, the subject's skin over the electrical stimulation site was prepared by cleaning with Alcohol Prep Pads (Dynarex; Orangeburg, NY, USA); then two 12-mm diameter Ag-AgCl surface electrodes (Model: Blue Sensor N; Ambu; Ballerup, Denmark) were placed on the muscle with a 20-mm center-to-center distance between the electrodes (Fig. 3). During electrical stimulation measurement, the FDS muscle was preconditioned with 2-Hz continuous electrical stimulation for 90 seconds in order to potentiate the muscle into a steady state where muscle twitch responses were relatively stable (Chang et al. 2009; Bennie et al. 2002; Adamo et al. 2009; Adamo et al. 2002; Thomsen et al. 2007). Then, five, 15-twitch trains of electrical stimulations were administered and the muscle's force response was measured (Chang et al. 2009).

The control condition was included to characterize the natural variability in the physiological response of the muscle across an 8-hour period. The control condition consisted of no computer work and only the temporal tasks and measurements outlined in

Fig. 2(a) were collected. In the control condition and recovery period, subjects were allowed to read books, listen to music, or watch movies in the laboratory.

On the keyboard use day, subjects were asked to type text from a book at their normal typing speed four times for 75 minutes (Fig. 2(b)). The text consisted of chapters from Grimm's Fairy Tales and had a Flesch-Kincaid grade level of 5.1 – 5.7 indicating the text would easily be understandable by an average twelve year old. All participants were given the same chapters to type but the order of chapters was randomized.

On the mouse use day, to strike a balance between boredom and providing a standardized task for subjects to perform, participants were asked to play the computer card game Solitaire four times for 75 minutes (Fig. 2(c)). The card game Solitaire was chosen since it required the user to engage in all the major mouse activities including moving the mouse, dragging objects, and clicking on the mouse button.

The two conditions described above allowed us to investigate whether there were different physiological responses when the FDS muscle was exposed to keyboard and/or mouse use. However, those two conditions performed in isolation may not well represent realistic computer use since both the keyboard and mouse are used together during normal computer operation. Therefore, on the combined keyboard and mouse use day, subjects were asked to alternatively use the mouse (play Solitaire) and keyboard (type text) for 15 minutes and 5 minute for four 75-minutes sessions (Fig. 2(d)). The proportion of keyboard and mouse use was determined based on previous studies showing that mouse use durations were typically four-fold longer than keyboard use (Chang et al. 2008; Mikkelsen et al. 2007; Chang et al. 2007).

Data analysis

Twitch forces and twitch durations (contraction, ½ relaxation, and total contraction time) were normalized to the pre-exercise, baseline measures obtained before each condition (0 minutes) to enable comparisons between the conditions. The statistical analysis was conducted in JMP (Version 8.0.2; SAS Institute Inc.; Cary, NC, USA). A *mixed model* with *restricted maximum likelihood estimation* (REML) was used to determine whether there were any differences in twitch force and/or twitch durations between the four conditions. In the model, subject was included as a random effect; measurement time and condition were treated as fixed effects. Since our primary interest was to determine whether muscle twitch responses changed after computer use, rather than using a Tukey post hoc which requires multiple pairwise comparisons, the *Dunnett's* test was used since it only compares the muscle twitch responses after computer use to the control, baseline measures. As subjective fatigue measures were not continuous (non-*Gaussian*) variables, *Friedman* test and post-hoc multiple comparisons (non-parametric repeated-measures ANOVA) in R (R 2.13.2, Development Core Team) were used to determine the effect of intensive computer use on subjective measures of muscle fatigue. Significance was noted when Type I error is less than 0.05.

Results

The results showed that there were significant differences between the conditions in twitch force, total twitch duration, contraction time, and ½ relaxation time (Table 1). All the twitch responses also differed over time. The interaction effect between condition and time was not significant for the twitch force, indicating that patterns of twitch force changes over time were not significantly different across the four different conditions. In contrast, the significant interaction effects between condition and time for total twitch duration, contraction time, and ½ relaxation time indicated that there were significant temporal differences across the four conditions. Detailed comparisons by condition are included in the next section.

Muscle twitch force

Comparisons of the normalized muscle twitch forces by the different exposure conditions are summarized in Fig. 4(a). In the control condition, FDS muscle twitch forces at 75 and 165 minutes (1.05 and 1.04 N, respectively) were approximately 10% higher than their initial measure (0.96 N) ($p = 0.02$ and 0.04, respectively). In the keyboard condition, FDS muscle twitch forces measured after the four typing sessions (1.29, 1.35, 1.28, and 1.35 N at 75, 165, 270, and 360 minutes, respectively) increased between 25 – 31% compared to the pre-exercise value (1.03 N) (p's < 0.01); then the forces decreased and returned towards pre-exercise levels during the recovery period. Alternatively, in the mouse condition, the muscle twitch forces increased approximately 25% after the first 75 minutes of mouse use (from 0.99 to 1.24 N, $p = 0.002$) and then declined in the following three 75-minute sessions. In the combined keyboard and mouse use condition, the twitch forces measured at 75, 165, 270, and 360 minutes (1.27, 1.25, 1.22, and 1.22, respectively) were 15 – 20% higher than the pre-exercise, baseline measure (1.06 N) (p's < 0.007); however, the forces decreased and returned towards pre-exercise levels during the recovery period.

Total twitch duration

The comparisons of the normalized total twitch durations are shown in Fig. 4(b). The total twitch durations (contraction + ½ relaxation times) were relatively stable in control condition averaging 103.8 (± 2.2) ms. The total twitch durations measured during keyboard use shortened by 3% at 360 minutes (from 102.8 to 99.6 ms, $p = 0.04$); then, the twitch durations gradually retuned to pre-exercise levels during the recovery period. In contrast, during mouse use, the total twitch duration lengthened up to 11% at 165 minutes (from 101.7 to 113 ms, $p < 0.0001$) and remained elevated during the 6 hours of mouse use (p's < 0.001), then returned towards the pre-exercise levels during the 2-hours of recovery. In the combined keyboard and mouse use condition, the total twitch duration lengthened by 5% with the total twitch durations measured at 75 (109.3 ms) and 165 minutes (109.6 ms) significantly longer than the pre-exercise (104.1 ms) measures ($p = 0.007$ and 0.01, respectively). Then, in the 2-hours of recovery, the total twitch durations returned towards the pre-exercise levels.

Contraction time

Changes in muscle contraction time by the different conditions and times are summarized in Fig. 4(c). Muscle contraction times were relatively stable in the control and keyboard conditions. However, in the mouse condition, the contraction times measured at 75, 165, and 270 minutes (56.6, 57.9, and 55.8 ms) were 3–7% longer than their pre-exercise values (54.0 ms) ($p = 0.0004$, $p < 0.0001$, and $p = 0.02$, respectively). In the combined keyboard and mouse condition, the contraction times lengthened and were significantly longer at 75 and 165 minutes (56.4 and 56.8 ms) compared to the pre-exercise measures (54.1 ms) ($p = 0.005$ and 0.0006, respectively).

One-half relaxation time

As shown in Fig. 4(d), in the exposure conditions, the normalized ½ relaxation times were more affected than the muscle contraction times. In the control condition, ½ relaxation times were relatively stable compared to the other conditions with no significant differences across the measurement periods. In the keyboard condition, ½ relaxation times systematically shortened ($p = 0.02$) and were approximately 5% shorter at 360 minutes (46.7 ms) compared to pre-exercise measures (49.1 ms); then, ½ relaxation times returned to the pre-exercise levels in the 2-hour recovery period. In contrast, in the mouse condition, ½ relaxation times measured after 75 minutes (52.3 ms) were 10% longer ($p < 0.0001$) than the pre-exercise measures (47.7 ms) and remained lengthened during 6 hours of mouse use periods relative to the pre-exercise measures (p's < 0.0002). During the 2-hour recovery period, the ½ relaxation times only recovered slightly and were still 6% longer at 390 and 420 minutes (50.8 and 50.5 ms, $p = 0.01$ and 0.04, respectively) than the pre-exercise measures. In the combined keyboard and mouse condition, ½ relaxation times did not significantly increase.

Subjective fatigue measures

Subjective fatigue ratings in all the body parts significantly differed across all the four conditions and over time (Table 2). The perceive fatigue ratings were lowest in the control condition and there were no significant differences in the fatigue ratings between the three experimental conditions. Across all the conditions, the perceive fatigue ratings on all the body parts increased over time during the computer use and decreased during recovery.

According to the post hoc tests, in the control condition, subjective peripheral fatigue measures in right hand, right wrist, right forearm, right shoulder, and neck were relatively stable and did not differ from their initial responses. Alternatively, in the other exposure conditions, subjective peripheral fatigue in hand, wrist, forearm, shoulder, and neck significantly increased (p's < 0.0001) during the four 75-minute blocks of exposure periods; then the subjective peripheral fatigue levels decreased in the recovery period but remained above the pre-exercise, baseline levels (Fig. 5). Across the exposure conditions, the intensive typing task (keyboard conditions) resulted in the greatest levels of subjective peripheral fatigue whereas combined keyboard and mouse use resulted in the lowest levels.

Discussion

The present study was conducted to determine whether 6 hours of intensive computer use caused any temporal changes in the physiological status of a targeted extrinsic finger muscle (right middle finger FDS) and whether any differences in these physiological changes existed between the different exposure conditions. Although the classical low-frequency fatigue (reduced twitch force and increased twitch duration) did not occur in this study, the results indicated that intensive keyboard use, mouse use, and combined mouse and keyboard use all caused temporal changes in the physiological response of the muscle with different precursor stages of low-frequency muscle fatigue being observed. With respect to the observed changes in the outcome measures, the greatest differences between conditions and with respect to time were seen in the twitch forces. With respect to the muscle contractile parameters, the most notable changes were in the ½ relaxation time measurements indicating that low force computer work may more selectively affect ½ relaxation times.

As expected, twitch durations and subjective peripheral fatigue did not change over time in the control condition when there was no physical exposure. However, despite no exposure, twitch forces in the control condition increased by 10% relative to pre-exercise, baseline measures. Chang et al (2009) also found that twitch forces of the FDS muscle changed during the control (no exercise) condition. This increased twitch force could have been due to simple diurnal changes caused by a gradual increase in the subjects' muscle temperature over the course of the experiment (He et al. 2000; Bennett 1985; De Ruiter and De Haan 2000). Nonetheless, the 10% increase in twitch force during the control condition was significantly less than the 20 to 30% increases measured in the other experimental conditions.

In the condition involving 6 hours of intensive keyboard use, muscle twitch durations systematically shortened whereas muscle twitch forces significantly increased. These temporal changes in twitch duration and force are typical features of muscle potentiation (Vandervoort et al. 1983; Garner et al. 1989; Miyamoto et al. 2011; Gossen and Sale 2000; Hamada et al. 2000a; Oleary et al. 1997; Green and Jones 1989); therefore, potentiation was the likely cause behind the increase in the force output of the muscle and a shortening of the muscle's contraction duration. The results indicated that dynamic muscle contractions associated with prolonged typing on the keyboard resulted in muscle potentiation (early-stage muscle fatigue).

After the first 75-minute session of intensive mouse use, both muscle twitch force increased and twitch duration significantly increased lengthened, indicating the coexistence of muscle potentiation and fatigue (as described in Fig. 1(c)). In the remaining three 75-minute blocks of mouse use, the twitch forces systematically decreased over time while twitch durations remained lengthened (Fig. 4(a, b)). As shown in Fig. 1, the decreased twitch force from potentiated levels and the lengthened twitch duration (Fig 1(c)) indicated that the muscle was in a state where potentiation and fatigue coexisted (Vandervoort et al. 1983; Fowles and Green 2003; Grange and Houston 1991; Rassier and Macintosh 2000). Furthermore, the systematic decline of the twitch force demonstrated that the physiological status of the muscle was on a path where if the exposure was long and intense enough, the potentiation

and fatigue could have given way and the muscle could have entered into a state of classical muscle fatigue (Fig. 1(e)).

These results showed that the temporal changes in muscle twitch force and twitch duration during mouse use were different from those during keyboard use. The twitch data showed that keyboard use resulted in the early-stage muscle fatigue (potentiation) whereas the mouse use induced more severe state of early-stage muscle fatigue (coexistence of potentiation and fatigue). This finding supports previous study findings that the mouse use is more strongly associated with MSDs, compared to keyboard use (Ijmker et al. 2007; Andersen et al. 2003; Kryger et al. 2003; Lassen et al. 2004). Although previous studies have argued that prolonged static load and longer usage duration may increase the association between mouse use and MSDs (Andersen et al. 2003; Jensen 2003; Kryger et al. 2003; Lassen et al. 2004), there has been lack of physiological evidence to objectively justify the argument. This study finding may provide some physiological evidence to help explain the different MSD associations with keyboard and mouse.

In the combined intensive keyboard and mouse condition, the physiological state of the muscle was between the levels measured from keyboard use (potentiation) and mouse use (potentiation and fatigue). As observed in the keyboard condition, the muscle twitch forces in the combined keyboard and mouse condition significantly increased and remained elevated compared to pre-exercise, baseline measurements. Similar to the changes in the mouse condition, in the combined keyboard and mouse condition, the muscle twitch durations also lengthened. Each 75-minute block in the combined keyboard and mouse use condition consisted of a series of blocks consisting of 15-minute mouse use followed by 5-minute keyboard use (Fig. 2(d)). This ratio of mouse to keyboard use occurs during actual computer work (Chang et al. 2008). Although the majority of the exposure was mouse operation, the fatigue level during the combined mouse and keyboard condition was not as pronounced as what was measured during the exclusive mouse use condition. The intermediate level of fatigue may be due to the physical variation in muscle loading created by switching between using the mouse and keyboard. Since monotonous and repetitive tasks are well-known risk factors for muscle fatigue and MSDs (Tayyari and Smith 1997; Ijmker et al. 2007), task variation is thought to be one of the more effective administrative ergonomic interventions (Tayyari and Smith 1997). Previous studies have shown that task variability may delay the onset and development of muscle fatigue (Srinivasan and Mathiassen 2012) and reduce muscle tissue damage through reperfusion of ischemic muscles (Visser and van Dieen 2006). The mixture of two different tasks may have increased the task variability and the resultant variability in muscle load and therefore resulted in the intermediate level of fatigue.

The results showed that ½ relaxation time lengthened in the mouse condition and the combined condition (keyboard and mouse) whereas ½ relaxation time systematically shortened in the keyboard condition (Fig. 4(c, d)). The ½ relaxation time is known to be sensitive to pH (Renaud and Stevens 1981; Pasquet et al. 2000) as high concentration of hydrogen ions (low pH) can slow down muscle relaxation (Allen et al. 1995). Relative to keyboard use which is more dynamic, the static posture and muscle loading during mouse operation may have resulted in greater metabolite concentrations (such as hydrogen

ions) and therefore contributed to the lengthening of the ½ relaxation times. Because a lengthening of ½ relaxation times is one of the common observations in fatigue studies (MacIntosh et al. 2006), the lengthening of ½ relaxation times observed in the mouse and the combined mouse and keyboard conditions may indicate the early onset of muscle fatigue. Moreover, the temporal changes in ½ relaxation times were greater and therefore had greater contribution to the temporal changes in the total twitch durations (contraction time + ½ relaxation time) compared to the contraction time. This finding is consistent with previous findings (MacIntosh et al. 2006; Celichowski et al. 2006) that the prolongation of muscle contraction times is predominantly due to a prolongation of ½ relaxation times.

Unlike the control condition where there were no significant changes in subjective peripheral fatigue measures over time, during computer input device use, the peripheral fatigue measures increased and then returned towards baseline levels in the two hour recovery period. There were more pronounced changes in the hand and wrist regions compared to the neck and shoulder. This finding is aligned with previous epidemiological studies which have shown that computer use was more strongly associated with hand and wrist symptoms than neck and shoulder symptoms (Ijmker et al. 2007; Gerr et al. 2004; Gerr et al. 2006). Although the results indicated that all three conditions of intensive computer use resulted in early precursor stages of muscle fatigue rather than classical muscle fatigue (decreased twitch force and lengthened contraction times), the subjective peripheral fatigue measures in hand and forearm appeared to be disproportionally high for early or intermediate precursor stages of muscle fatigue as compared to the changes in the twitch force and contraction time. Previous studies (Valencia 1986; Greening and Lynn 1998) have shown that the subjective sense of peripheral fatigue is not necessarily synchronized with the objective measurement of muscle fatigue. Even low concentrations of metabolites produced by muscle contraction could increase blood pressures in the muscle (Alam and Smirk 1937). Sensory afferents could detect both the contraction-produced metabolites and increase blood pressure in the muscle; consequently, the sensation of muscle fatigue could increase (Light et al. 2010). At this early stage, the muscle twitch force and twitch duration may not be affected by the low concentrations of metabolites. This argument can be supported by a previous study (Valencia 1986) finding that subjective muscle discomfort preceded the measurement of peripheral muscle fatigue.

Similar to the results in this study, when human subjects have been exposed to long duration (30 minutes) relatively low intensity exercise (15% MVC), the time–course for post-exercise potentiation recovery has been shown to be quite long taking up to 60 minutes (Chang et. al. 2009. In contrast, after shorter duration with moderate to maximal exercise (> 30% MVC), post-exercise muscle potentiation appears to be much shorter in duration, lasting 10 minutes or less (Green and Jones 1989; Fowles and Green 2003). Other studies have shown that potentiation duration can be affected by various factors such as intensity, duration, and frequencies of the exercise (Grange and Houston 1991; Fowles and Green 2003).

Additionally, in the mouse use condition, ½ relaxation times were lengthened and did not completely recover to the pre-exercise levels during the two-hour recovery period (Fig. 4(d)). This persistent prolongation of ½ relaxation times is known to be associated with impairment in the sarcoplasmic reticulum Ca2+ uptake (Sjoholm et al. 1983). As the

prolonged ½ relaxation time indicates onset of muscle fatigue (MacIntosh et al. 2006), this delayed recovery of ½ relaxation time may suggest the delayed recovery of muscle fatigue, which is one of the key characteristics of low-frequency fatigue (LFF) (Edwards et al. 1977). This delayed fatigue recovery may indicate that the mouse use caused early stage of LFF and that the five hours of mouse use may require at least two hours of rest for the muscle to recover. Chang et al. (2009) also showed that 15 %MVC fatiguing exercise induced LFF and that it took longer than one hour for twitch forces and ½ relaxation time to recover to baseline levels.

The limitations of this study include generalizing the findings to computer use in actual occupational settings and limitations associated with electrical stimulation of the muscle. First, all the computer use conditions were standardized to minimize task-specific effects on muscle fatigue. However, the standardized tasks may not represent realistic occupational computer work; therefore, it is not clear if the physiological changes observed in this laboratory-based study will be similar to these changes under actual occupational computer use. Second, muscle fatigue was evaluated in only one muscle (FDS); therefore, the interpretations of study findings should be limited to the FDS muscle. FDS muscle was chosen because 1) repetitive and static movements during computer use are mainly driven by extrinsic finger muscles in the forearm; 2) FDS muscle is superficial that it can be readily and non-invasively stimulated with surface electrodes; 3) epidemiological studies have shown that computer use is strongly associated with musculoskeletal symptoms in hand/arm regions. However, since computer use can affect other muscles (e.g. extensors) and other body regions such as the neck and shoulder regions, studying other muscles and body regions may be merited. Lastly, electrical stimulation may have affected physiological changes of the muscle as previous studies noted (Dennerlein et al. 2003; Chang et al. 2009). However, as the intensity and duration of the computer tasks were much longer and greater compared to the administration of the electrical stimulation, therefore the fatigue effects associated with the electrical stimulation were likely negligible.

Conclusions

The results showed that 6 hours of actual computer use caused physiological changes in the FDS muscle and that the physiological changes observed during mouse use were more substantial compared to keyboard use. Despite the absence of classical muscle fatigue during actual computer use, the accumulation of the physiological changes observed in this study may be eventually associated with the development of classical muscle fatigue. Therefore, the difference physiological changes of FDS muscle between keyboard and mouse use found in the present study may provide physiological evidence to support the previous findings that the mouse use is more strongly associated with MSDs than the keyboard use.

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References

Adamo DE, Khodaee M, Barringer S, Johnson PW, Martin BJ (2009) Low mean level sustained and intermittent grip exertions: Influence of age on fatigue and recovery. Ergonomics 52 (10):1287–1297. [PubMed: 19662553]

Adamo DE, Martin BJ, Johnson PW (2002) Vibration-induced muscle fatigue, a possible contribution to musculoskeletal injury. European Journal of Applied Physiology 88 (1–2):134–140. [PubMed: 12436281]

Alam M, Smirk FH (1937) Observations in man upon a blood pressure raising reflex arising from the voluntary muscles. Journal of Physiology-London 89 (4):372–383

Allen DG, Lee JA, Westerblad H (1989) Intracellular calcium and tension during fatigue in isolated single muscle fibres from Xenopus laevis. J Physiol The Journal of Physiology 415:433–458

Allen DG, Westerblad H, Lannergren J (1995) The role of intracellular acidosis in muscle fatigue. Advances in Experimental Medicine and Biology; Fatigue: Neural and muscular mechanisms 384:57–68

Alway SE, Hughson RL, Green HJ, Patla AE, Frank JS (1987) Twitch potentiation after fatiguing exercise in man. European Journal of Applied Physiology and Occupational Physiology 56 (4):461–466 [PubMed: 3622489]

Andersen JH, Fallentin N, Thomsen JF, Mikkelsen S (2011) Risk factors for neck and upper extremity disorders among computers users and the effect of interventions: an overview of systematic reviews. Plos One 6 (5):11.

Andersen JH, Thomsen JF, Overgaard E, Lassen CF, Brandt LPA, Vilstrup I, Kryger AI, Mikkelsen S (2003) Computer use and carpal tunnel syndrome - A 1-year follow-up study. Jama-Journal of the American Medical Association 289 (22):2963–2969

Armstrong TJ, Buckle P, Fine LJ, Hagberg M, Jonsson B, Kilbom A, Kuorinka IAA, Silverstein BA, Sjogaard G, Viikarijuntura ERA (1993) A comceptional-model for work-related neck and upper-limb musculoskeletal disorders. Scandinavian Journal of Work Environment & Health 19 (2):73–84

Bennett AF (1985) Temperature and muscle. The Journal of experimental biology 115:333–344 [PubMed: 3875678]

Bennie KJ, Ciriello VM, Johnson PW, Dennerlein JT (2002) Electromyographic activity of the human extensor carpi ulnaris muscle changes with exposure to repetitive ulnar deviation. European Journal of Applied Physiology 88 (1–2):5–12. [PubMed: 12436265]

Bergqvist U, Wolgast E, Nilsson B, Voss M (1995) The influence of VDT work on musculoskeletal disorders. Ergonomics 38 (4):754–762 [PubMed: 7729402]

Borg GA (1982) Psychophysical bases of perceived exertion. Medicine and science in sports and exercise 14 (5):377–381 [PubMed: 7154893]

Celichowski J, Pogrzebna M, Krutki P (2006) Changes in the time course of potentiated and fatigued contractions of fast motor units in rat muscle. Archives Italiennes De Biologie 144 (3–4):159–171 [PubMed: 16977831]

Chang CH, Amick BC, Menendez CC, Katz JN, Johnson PW, Robertson M, Dennerlein JT (2007) Daily computer usage correlated with undergraduate students' musculoskeletal symptoms. American Journal of Industrial Medicine 50 (6):481–488. [PubMed: 17450542]

Chang CH, Johnson PW, Dennerlein JT (2008) A Wide Range of Activity Duration Cutoffs Provided Unbiased Estimates of Exposure to Computer Use. Journal of Occupational and Environmental Hygiene 5 (12):790–796. [PubMed: 18932082]

Chang CH, Johnson PW, Katz JN, Eisen EA, Dennerlein JT (2009) Typing keystroke duration changed after submaximal isometric finger exercises. European Journal of Applied Physiology 105 (1):93–101. [PubMed: 18853179]

De Ruiter CJ, De Haan A (2000) Temperature effect on the force/velocity relationship of the fresh and fatigued human adductor pollicis muscle. Pflugers Archiv-European Journal of Physiology 440 (1):163–170. [PubMed: 10864011]

Dennerlein JT, Ciriello VM, Kerin KJ, Johnson PW (2003) Fatigue in the forearm resulting from low-level repetitive ulnar deviation. AIHA Journal 64 (6):799–805 [PubMed: 14674796]

Dennerlein JT, Diao E, Mote CD, Rempel DM (1998) Tensions of the flexor digitorum superficialis are higher than a current model predicts. Journal of Biomechanics 31 (4):295–301 [PubMed: 9672082]

Dennerlein JT, Diao E, Mote CD, Rempel DM (1999) In vivo finger flexor tendon force while tapping on a keyswitch. Journal of Orthopaedic Research 17 (2):178–184 [PubMed: 10221833]

Edwards RHT, Hill DK, Jones DA, Merton PA (1977) Fatigue of long duration in human skeletal muscle after exercise. The Journal of physiology 272 (3):769–778 [PubMed: 592214]

Enoka RM (2002) Neuromechanics of human movement. Human Kinetics, Champaign, IL

Fowles JR, Green HJ (2003) Coexistence of potentiation and low-frequency fatigue during voluntary exercise in human skeletal muscle. Canadian Journal of Physiology and Pharmacology 81 (12):1092–1100. [PubMed: 14719027]

Garner SH, Hicks AL, McComas AJ (1989) Prolongation of twitch potentiating mechanism throughout muscle fatiuge and recovery. Experimental Neurology 103 (3):277–281 [PubMed: 2920793]

Gerr F, Marcus M, Ensor C, Kleinbaum D, Cohen S, Edwards A, Gentry E, Ortiz DJ, Monteilh C (2002) A prospective study of computer users: I. study design and incidence of musculoskeletal symptoms and disorders. American Journal of Industrial Medicine 41:221–235 [PubMed: 11920966]

Gerr F, Marcus M, Monteilh C (2004) Epidemiology of musculoskeletal disorders among computer users: lesson learned from the role of posture and keyboard use. Journal of Electromyography and Kinesiology 14 (1):25–31. [PubMed: 14759747]

Gerr F, Monteilh CP, Marcus M (2006) Keyboard use and musculoskeletal outcomes among computer users. Journal of Occupational Rehabilitation 16 (3):265–277. [PubMed: 16802184]

Gossen ER, Sale DG (2000) Effect of postactivation potentiation on dynamic knee extension performance. European Journal of Applied Physiology 83 (6):524–530 [PubMed: 11192060]

Grange RW, Houston ME (1991) Simultaneous potentiation and fatigue in quadriceps after a 60 second maximal voluntary isometric contraction. Journal of Applied Physiology 70 (2):726–731 [PubMed: 2022565]

Grange RW, Vandenboom R, Houston ME (1993) Physiological significance of myosin phosphorylation in skeletal-muscle. Canadian Journal of Applied Physiology-Revue Canadienne De Physiologie Appliquee 18 (3):229–242 [PubMed: 8242003]

Green HJ, Jones SR (1989) Does post-tetanic potentiation compensate for low-frequency fatigue. Clinical Physiology 9 (5):499–514 [PubMed: 2582735]

Greening J, Lynn B (1998) Vibration sense in the upper limb in patients with repetitive strain injury and a group of at-risk office workers. International Archives of Occupational and Environmental Health 71 (1):29–34 [PubMed: 9523246]

Hamada T, Sale DG, Macdougall JD (2000a) Postactivation potentiation in endurance-trained male athletes. Medicine and Science in Sports and Exercise 32 (2):403–411 [PubMed: 10694124]

Hamada T, Sale DG, MacDougall JD, Tarnopolsky MA (2000b) Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. Journal of Applied Physiology 88 (6): 2131–2137 [PubMed: 10846027]

Hanchard NCA, Williamson M, Caley RW, Cooper RG (1998) Electrical stimulation of human tibialis anterior: (A) contractile properties are stable over a range of submaximal voltages; (B) high- and low-frequency fatigue are inducible and reliably assessable at submaximal voltages. Clinical Rehabilitation 12 (5):413–427 [PubMed: 9796932]

He ZH, Bottinelli R, Pellegrino MA, Ferenczi MA, Reggiani C (2000) ATP consumption and efficiency of human single muscle fibers with different myosin isoform composition. Biophysical Journal 79 (2):945–961 [PubMed: 10920025]

Houston ME, Green HJ, Stull JT (1985) Myosin light chain phosphorylation and isometric twitch potentiation in intact human-muscle. Pflugers Archiv-European Journal of Physiology 403 (4):348–352 [PubMed: 3839303]

Ijmker S, Huysmans MA, Blatter BM, van der Beek AJ, van Mechelen W, Bongers PM (2007) Should office workers spend fewer hours at their computer? A systematic review of the literature. Occupational and Environmental Medicine 64 (4):211–222. [PubMed: 17095550]

Jensen C (2003) Development of neck and hand-wrist symptoms in relation to duration of computer use at work. Scandinavian Journal of Work Environment & Health 29 (3):197–205

Jensen C, Finsen L, Sogaard K, Christensen H (2002) Musculoskeletal symptoms and duration of computer and mouse use. International Journal of Industrial Ergonomics 30 (4–5):265–275

Johnson PW, Ciriello VM, Kerin KJ, Dennerlein JT (2012) Using electrical stimulation to measure physiological changes in the human extensor carpi ulnaris muscle after prolonged low-level repetitive ulnar deviation. Applied Ergonomics 44(1): 35–41 [PubMed: 22595493]

Jones DA (1996) High- and low-frequency fatigue revisited. Acta physiologica Scandinavica 156 (3):265–270 [PubMed: 8729686]

Kryger AI, Andersen JH, Lassen CF, Brandt LPA, Vilstrup I, Overgaard E, Thomsen JF, Mikkelsen S (2003) Does computer use pose an occupational hazard for forearm pain; from the NUDATA study. Occupational and Environmental Medicine 60:e14 [PubMed: 14573725]

Lassen CF, Mikkelsen S, Kryger AI, Brandt LPA, Overgaard E, Thomsen JF, Vilstrup L, Andersen JH (2004) Elbow and wrist/hand symptoms among 6,943 computer operators: A 1-year follow-up study (The NUDATA study). American Journal of Industrial Medicine 46 (5):521–533. [PubMed: 15490472]

Light AR, Vierck CJ, Light KC (2010) Myalgia and Fatigue: Translation from Mouse Sensory Neurons to Fibromyalgia and Chronic Fatigue Syndromes. In: Translational Pain Research: From Mouse to Man. CRC Press, Boca Raton, FL,

Lin MI, Liang HW, Lin KH, Hwang YH (2004) Electromyographical assessment on muscular fatigue - an elaboration upon repetitive typing activity. Journal of Electromyography and Kinesiology 14 (6):661–669. [PubMed: 15491841]

MacIntosh BR, Gardiner PF, McComas AJ (2006) Skeletal muscle : form and function. Human Kinetics, Champaign, IL

MacIntosh BR, Rassier DE (2002) What is fatigue? Canadian journal of applied physiology = Revue canadienne de physiologie appliquée 27 (1):42–55 [PubMed: 11880690]

Martin BJ, Armstrong TJ, Foulke JA, Natarajan S, Klinenberg E, Serina E, Rempel D (1996) Keyboard reaction force and finger flexor electromyograms during computer keyboard work. Human Factors 38 (4):654–664 [PubMed: 8976628]

McLoone HE, Jacobson M, Clark P, Opina R, Hegg C, Johnson P (2009) Design and evaluation of a curved computer keyboard. Ergonomics 52 (12):1529–1539. [PubMed: 19941185]

Metzger JM, Greaser ML, Moss RL (1989) Variations in cross-bridge attachment rate and tension with phosphorylation of myosin in mammalian skinned skeletal-muscle fibers - implications for twtich potentiation in intact muscle. Journal of General Physiology 93 (5):855–883 [PubMed: 2661721]

Mikkelsen S, Vilstrup I, Lassen CF, Kryger AI, Thomsen JF, Andersen JH (2007) Validity of questionnaire self-reports on computer, mouse and keyboard usage during a four-week period. Occupational and Environmental Medicine 64:541–547 [PubMed: 17387136]

Miyamoto N, Yanai T, Kawakami Y (2011) Twitch potentiation induced by stimulated and voluntary isometric contractions at various torque levels in human knee extensor muscle. Muscle & Nerve 43 (3):360–366. [PubMed: 21321952]

Oleary DD, Hope K, Sale DG (1997) Posttetanic potentiation of human dorsiflexors. Journal of Applied Physiology 83 (6):2131–2138 [PubMed: 9390991]

Palmer BM, Moore RL (1989) Myosin light chain phosphorylation and tension potentiation in mouse skeletal-muscle. American Journal of Physiology 257 (5):C1012–C1019 [PubMed: 2596580]

Pasquet B, Carpentier A, Duchateau J, Hainaut K (2000) Muscle fatigue during concentric and eccentric contractions. Muscle & Nerve 23 (11):1727–1735 [PubMed: 11054752]

Punnett L, Wegman DH (2004) Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. Journal of Electromyography and Kinesiology 14 (1):13–23. [PubMed: 14759746]

Radwin RG, Jeng OJ (1997) Activation force and travel effects on overexertion in repetitive key tapping. Human Factors 39 (1):130–140 [PubMed: 9302885]

Rankin LL, Enoka RM, Volz KA, Stuart DG (1988) Coexistance of twitch potentiation and tetanic force decline in rat hindlimb muscle. Journal of Applied Physiology 65 (6): 2687–2695 [PubMed: 3215868]

Rassier DE, Macintosh BR (2000) Coexistence of potentiation and fatigue in skeletal muscle. Brazilian Journal of Medical and Biological Research 33 (5):499–508 [PubMed: 10775880]

Rempel D, Serina E, Klinenberg E, Martin BJ, Armstrong TJ, Foulke JA, Natarajan S (1997) The effect of keyboard keyswitch make force on applied force and finger flexor muscle activity. Ergonomics 40 (8):800–808 [PubMed: 9336104]

Rempel DM, Harrison RJ, Barnhart S (1992) Work-related cumulative trauma disorders of the upper extremity. Jama-Journal of the American Medical Association 267 (6):838–842

Renaud JM, Stevens ED (1981) The interactive effects of temperature and ph on the isometric contraction of toad sartorius muscle. Journal of Comparative Physiology 145 (1):67–71

Sjoholm H, Sahlin K, Edstrom L, Hultman E (1983) Quantitative estimation of anaerobic and oxidative energy-metabolism and contraction characteristics in intact human skeletal-muscle in response to electrical-stimulation. Clinical Physiology 3 (3):227–239. [PubMed: 6683608]

Smutz P, Serina E, Rempel D (1994) A sytesm for evaluating the effect of keyboard design on force, posture, comport, and productivity. Ergonomics 37 (10): 1649–1660.

Srinivasan D, Mathiassen SE (2012) Motor variability in occupational health and performance. Clinical Biomechanics 27 (10):979–993. [PubMed: 22954427]

Sweeney HL, Stull JT (1990) Alteration of cross-bridge kinetics by myosin light chain phosphorylation in rabbit skeletal-muscle - implication for regulation of actin myosin interaction. Proceedings of the National Academy of Sciences of the United States of America 87 (1):414–418 [PubMed: 2136951]

Takala EP (2002) Static muscular load, an increasing hazard in modern information technology. Scandinavian Journal of Work Environment & Health 28 (4):211–213

Tayyari F, Smith JL (1997) Occupational ergonomics : principles and applications. Manufacturing systems engineering series. Chapman & Hall, London

Thomsen GF, Johnson PW, Svendsen SW, Kryger AI, Bonde JPE (2007) Muscle fatigue in relation to forearm pain and tenderness among professional computer users. Journal of Occupational Medicine and Toxicology 2 (17)

Valencia F (1986) Local muscle fatigue. A precursor to RSI? The Medical journal of Australia 145 (7):327–330 [PubMed: 3531787]

Vandervoort AA, Quinlan J, McComas AJ (1983) Twitch potentiation after voluntary contraction. Experimental Neurology 81 (1):141–152 [PubMed: 6861942]

Visser B, van Dieen JH (2006) Pathophysiology of upper extremity muscle disorders. Journal of Electromyography and Kinesiology 16 (3):312–312.

Waersted M, Hanvold TN, Veiersted KB (2010) Computer work and musculoskeletal disorders of the neck and upper extremity: A systematic review. BMC Musculoskeletal Disorders 11:79. [PubMed: 20429925]

Westerblad H, Bruton JD, Allen DG, Lannergren J (2000) Functional significance of Ca2+ in long-lasting fatigue of skeletal muscle. European Journal of Applied Physiology 83 (2–3):166–174 [PubMed: 11104057]

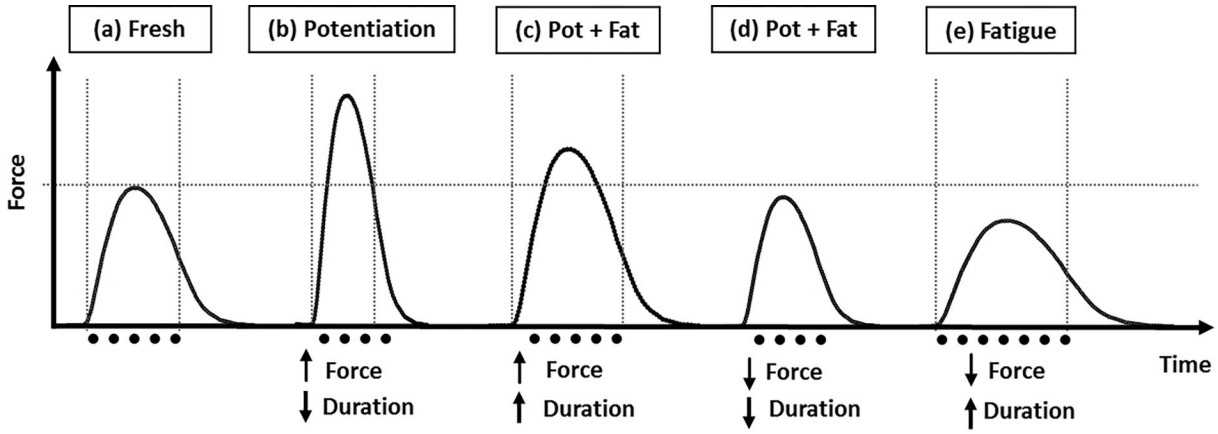

Fig 1.

Schematic representation of the temporal stages leading to muscle fatigue: (a) fresh, (b) potentiated, (c) potentiated and fatigued (increase in force and contraction duration), (d) potentiated and fatigued (decrease in force and contraction duration), and (e) fatigued. Each stage indicates a progression in the severity of the fatigue. Stages (b), (c), (d) and (e) are transient states which are dependent on the type of fatiguing exercise. Typically some combination of stages (b), (c), (d) and (e) will be measured but the muscle will not necessarily go through all five stages.

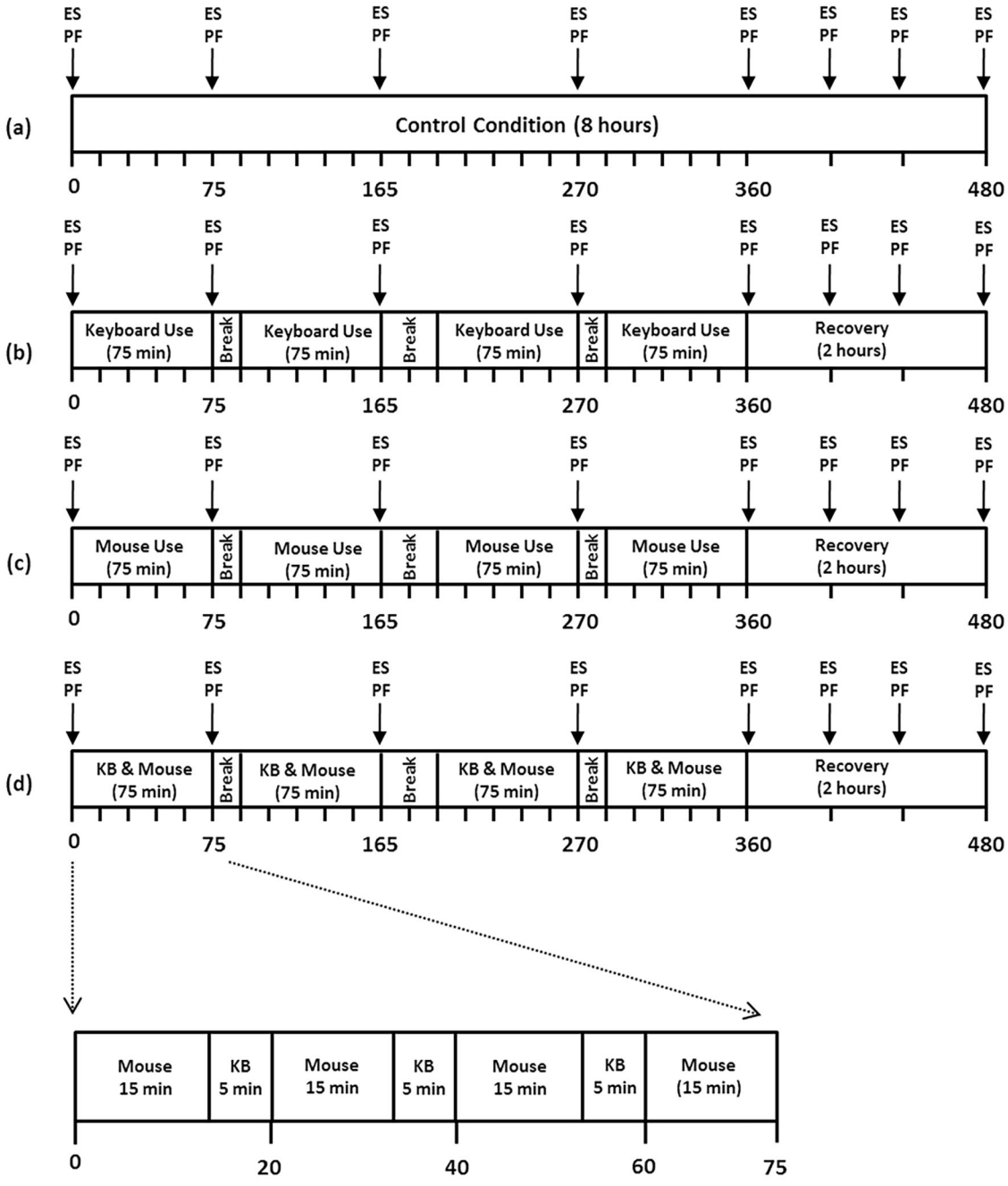

Fig 2.

Experimental design: (a) control condition, (b) keyboard condition, (c) mouse condition, and (d) the combined mouse and keyboard condition. At the beginning of the experiment, during the breaks and in a two-hour recovery period, the force response of the muscle to electrical stimulation (ES) and self-reported their peripheral muscle fatigue (PF) were measured

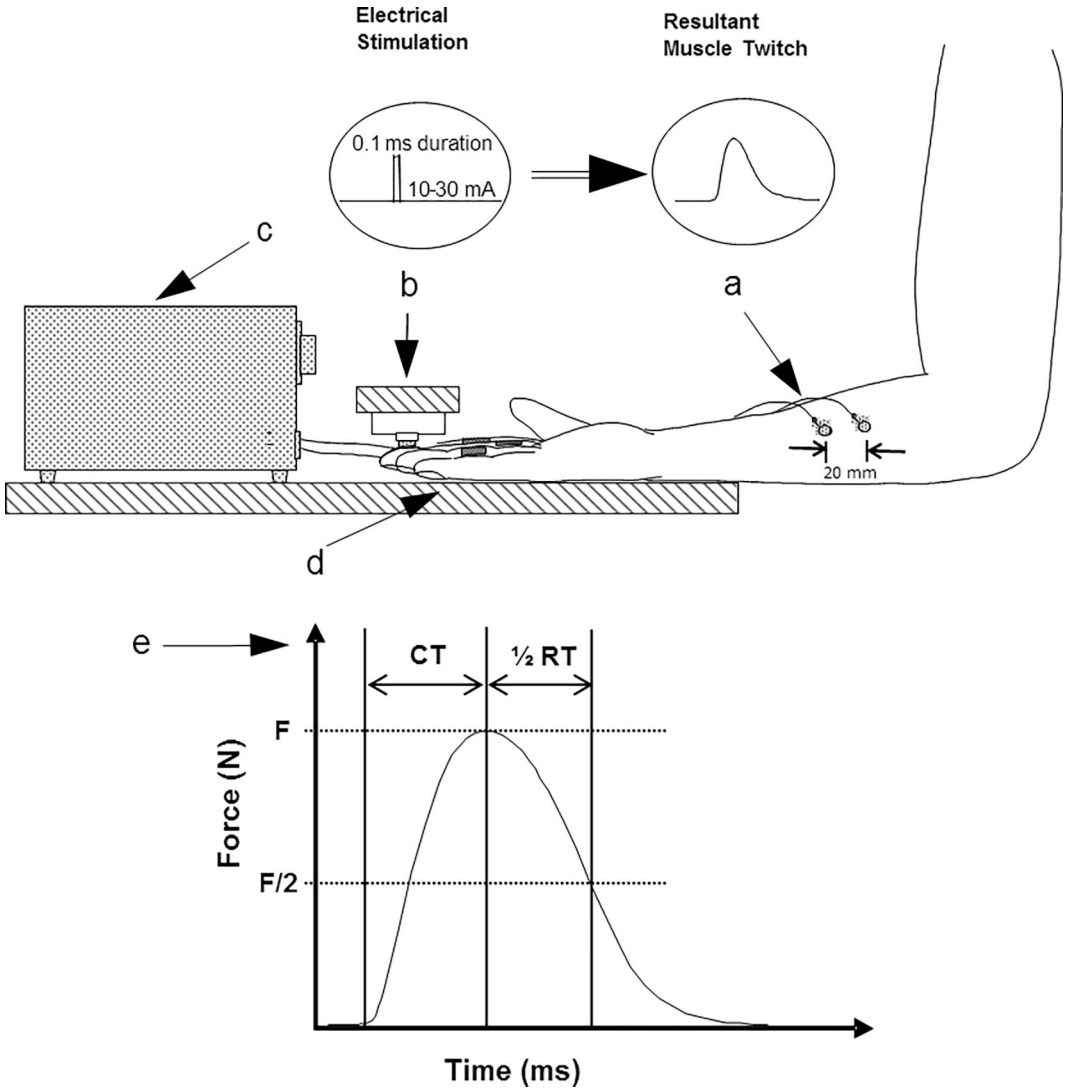

Fig 3.

Diagram of the twitch measurement apparatus as seen from the side and twitch force measures: (a) surface electrodes over FDS; (b) force transducer over the middle finger; (c) electrical stimulator; (d) restraining jig; (e) twitch force profile: F (twitch force), CT (contraction time), ½ RT (½ relaxation time), and total contraction duration (CT + ½ RT). Inserts show the electrical stimulation and the resultant muscle twitch

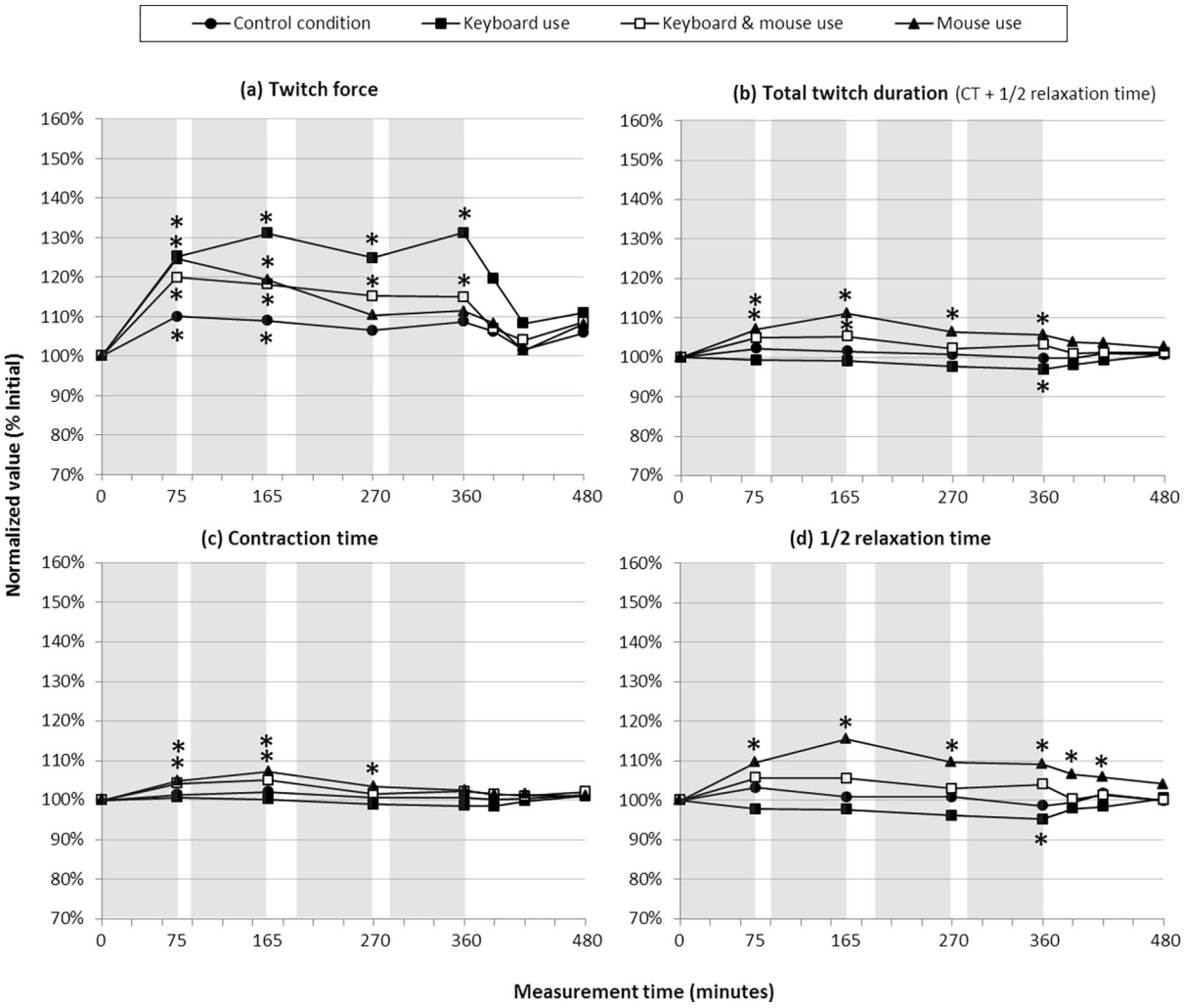

Fig 4.

Comparisons of the normalized muscle contraction responses by the four different exposure conditions [n = 18]: (a) twitch force, (b) total twitch duration (contraction time + ½ relaxation time), (c) contraction time, (d) ½ relaxation time. Shaded columns indicate 75-minute blocks of exposure time (keyboard or mouse use); white columns indicate the rest breaks between the blocks (15, 30, and 15 minutes, respectively) and the two-hour recovery periods. All the values normalized by the initial values at time 0. Asterisks denote statistically significant differences from baseline measures at time 0 ($p < 0.05$). Standard error bars were omitted for clarity

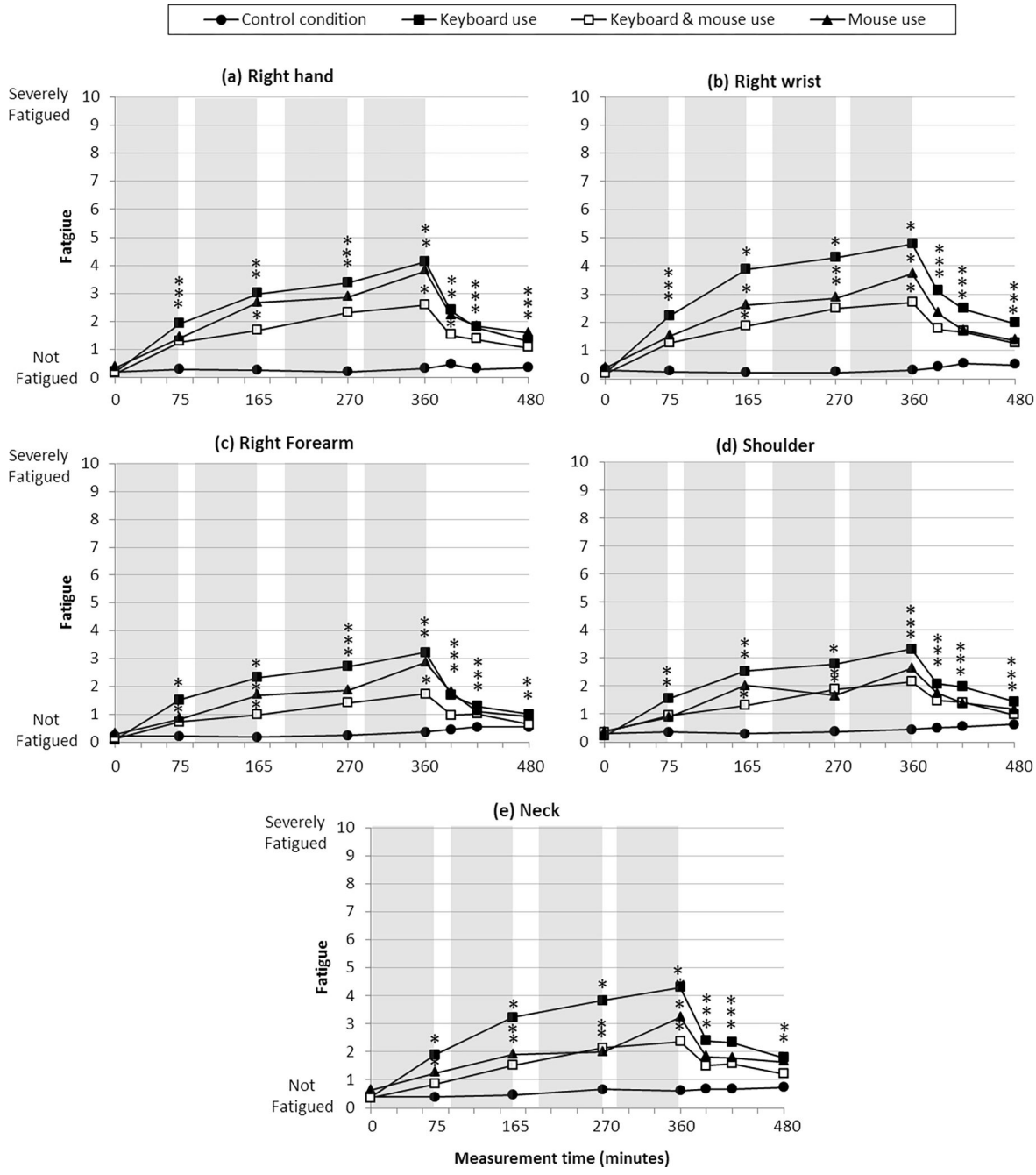

Fig 5.

Changes in subjective peripheral muscle fatigue measures [n = 18]. Shaded columns indicate 75-minute blocks of exposure time (keyboard and/or mouse use); white columns indicated the rest breaks between the blocks (15, 30, and 15 minutes, respectively) and the two-hour recovery periods. All the values normalized by the initial values at time 0. Asterisks denote statistically significant differences from baseline measures at time 0 ($p < 0.05$). Standard error bars were omitted for clarity

Table1.

Mean (Standard Error) and the p-values for the muscle twitch forces (N), total twitch durations (contraction time + ½ relaxation times in milliseconds: ms), contraction times (ms), and ½ relaxation times (ms) across conditions, followed by the p-values for time and the condition by time interactions. Asterisks denote statistical significance ($p < 0.05$).

Effect		Twitch Force	Twitch duration	Contraction time	1/2 relaxation time
Condition	Control	1.02 (0.04)	103.83 (0.89)	54.37 (0.34)	49.45 (0.63)
	Keyboard	1.22 (0.06)	101.66 (0.72)	53.57 (0.26)	48.09 (0.51)
	Keyboard & Mouse	1.17 (0.05)	106.58 (0.94)	55.34 (0.33)	51.24 (0.67)
	Mouse	1.10 (0.05)	106.75 (0.91)	55.45 (0.37)	51.30 (0.61)
	P-value	0.0179*	0.0012*	0.0033*	0.0027*
Time	P-value	<0.0001*	0.0002*	<0.0001*	0.0062*
Condition × Time	P-value	0.1802	<0.0001*	0.0011*	<0.0001*

Table 2.

Mean (Standard Error) and the p-values for differences in subjective peripheral fatigue ratings in the right hand, wrist, forearm, shoulder and neck, followed by the p-values for time and the condition by time interactions.. A Borg CR-10 scale was used with 0 being no fatigue and 10 being extremely fatigued. Asterisks denote statistical significance ($p < 0.05$).

Effect		Hand	Wrist	Forearm	Shoulder	Neck
Condition	Control	0.3 (0.04)	0.3 (0.05)	0.3 (0.06)	0.4 (0.07)	0.6 (0.07)
	Keyboard	2.3 (0.17)	2.9 (0.19)	1.8 (0.14)	2 (0.17)	2.5 (0.18)
	Keyboard & Mouse	1.5 (0.14)	1.6 (0.15)	1.0 (0.11)	1.3 (0.13)	1.4 (0.13)
	Mouse	2.1 (0.16)	2.1 (0.17)	1.4 (0.14)	1.5 (0.14)	1.8 (0.16)
	P-value	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*
Time	P-value	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*
Condition × Time	P-value	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*