FINAL PROGRESS REPORT

April 19, 2012

Award Number : R21 OH009088-01A1

Project Sponsor: NIOSH

Title: Non-invasive continual computer exposure assessment tool

Project Start and End Date: 1 September 2008 to 31 August 2011.

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Contents

Abstract

The long-term objective of this exploratory grant was to create software to continually monitor the digital signals from the mouse and keyboard in order to determine whether small, systematic changes in mouse button-click and keystroke durations occur, which may be associated with objective fatigue-related changes in the muscle. If systematic, fatigue-related changes can be detected in the digital signals from the mouse and keyboard, the operator's own computer could monitor and detect these temporal changes and then proactively notify the user that they may benefit from a change in activities, mitigating potentially adverse changes in the muscle and thereby potentially reducing the operator's subsequent chances for developing a computer-related musculoskeletal disorder.

Repeatedly using the same eighteen subjects, the specific aims of this project were to: 1) determine whether keystroke duration systematically changed as the exposure to keyboard work increased and whether the temporal changes in keystroke durations paralleled objective measures of muscle fatigue - changes in muscle's force output and contraction duration in response to electrical stimulation, 2) determine whether mouse button-click duration systematically changed as the exposure to mouse work increased and paralleled objective measures of muscle fatigue, and 3) determine whether combined mouse and keyboard work cause temporal changed in keystroke and/or mouse button-click duration and paralleled objective measures of muscle fatigue.

Based on the objective measures of muscle fatigue (the muscle's force response to electrical stimulation), the results indicated that intensive keyboard use, intensive mouse use, and combined intensive mouse and keyboard use all caused muscle fatigue; however, differing stages of muscle fatigue were observed. In the condition involving six hours of intensive keyboard use, keystroke durations systematically shortened paralleling the objective measures of early-stage muscle fatigue. Early-stage muscle fatigue was characterized by an increase in the force output of the muscle and a shortening of the muscle's contraction. In the condition involving six hours of intensive mouse use, systematic changes in mouse button click durations were not observed, but muscle fatigue was more pronounced, as compared to the keyboard condition. Finally, in the combined intensive mouse and keyboard condition, the muscle was fatigued, and the level of muscle fatigue was between what was measured during keyboard use (early-stage fatigue) and mouse use (intermediate-stage fatigue). Systematic changes in keystroke durations occurred and paralleled the temporal changes in muscle twitch durations indicating early-stage muscle fatigue; however, mouse button-click durations did not changed and reflect the measured changes in twitch duration.

The important outcome of this study was documenting that muscle fatigue did result from intensive mouse, keyboard use and combined mouse and keyboard use. Intensive mouse use was associated with the greatest levels of muscle fatigue and paralleled injury trends seen in the workforce - a greater number and a greater severity of injuries are associated with mouse use. Preliminary results indicate that, by monitoring for systematic changes in keystroke duration, we may be able to turn the computer operator's own keyboard into an exposure assessment device which may ultimately reduce keyboard-related injuries. Using the mouse-button click duration in a similar fashion was not successful but merits further investigation.

Highlights/Significant Findings:

Aim 1 - The six hours of intensive keyboard use resulted in early-stage muscle fatigue, characterized by an increase in the muscle's force output and a shortening of the muscle contraction duration. However, due to the small changes in the muscle contraction duration, the changes in keystroke durations did not reflect the temporal changes in muscle contraction duration.

Aim 2 - The six hours of intensive mouse use resulted in more pronounced muscle fatigue compared to the keyboard condition (intermediate-stage fatigue – increased contraction force and lengthened contraction duration). The increased muscle contraction durations paralleled the temporal changes in keystroke durations but not the temporal changes in mouse button click durations.

Aim 3 - In the combined intensive mouse and keyboard condition, the muscle was fatigued, and the level of muscle fatigue was between what was measured during keyboard use (early-stage muscle fatigue) and mouse use (intermediate-stage muscle fatigue). A systematic lengthening of the muscle contraction duration was observed and paralleled the systematic lengthening in keystroke durations.

All Aims – Based on the muscle's twitch force response to electrical stimulation, this study demonstrated that mouse use caused greater physiological changes in the muscle (i.e. muscle fatigue), than exclusive keyboard use or combined mouse and keyboard use. While subtle changes in keystroke durations (voluntary muscle contractions) often coincided with the subtle changes in the muscle's twitch contraction response to electrical stimulation (involuntary muscle contractions), mouse button-click durations were less robust in paralleling the temporal changes in twitch contraction durations indicative of muscle fatigue and recovery. In the control condition where subjects were not exposed to any computer activity and the same measurements (muscle twitches, keystroke durations and mouse button click durations) were collected, all measurements were relatively stable and did not change with time. The lack of changes in the control condition and the temporal changes measured in Aims 1 – 3 indicated the temporal changes were related to changes in the physiological state of the muscle (muscle fatigue) and the result of intensive computer input device use.

Translation of Findings: During the six hours of mouse use and combined intensive mouse and keyboard use, keystroke durations systematically lengthened, and returned towards the baseline pre-exposure duration during the two hours of recovery. The corresponding objective measure of muscle fatigue (muscle twitch contraction durations) paralleled the systematic changes in keystroke durations throughout the six hours of keyboard use and two hours of recovery. If a systematic lengthening in keystroke duration, as measured in this study, are indicative of early stage muscle fatigue and a precursor to more severe computer related injuries, then the operator's own computer could monitor and identify when there is a systematic lengthening of keystroke durations and proactively notify the user that they may benefit from a change in activities, thereby potentially reducing the operator's subsequent chances for developing a computer-related musculoskeletal disorder. To validate using the subject's own keyboard as an exposure assessment device to reduce an operator's chances of developing a subsequent musculoskeletal disorder, different durations and intensities of keyboard work should best tested in controlled laboratory studies and then subsequent studies, adequately powered should be conducted in less controlled more realistic field settings. In addition, the cumulative effect of computer use and systematic changes in keystroke durations should be evaluated over longer periods of time (e.g. multiple days, weeks or months).

The mouse only condition was associated with the greatest levels of muscle fatigue; and the greater fatigue in the mouse only condition parallels prior injury trends seen in the workforce - a greater number and severity of injuries are associated with mouse use. The muscle fatigue results indicated that exclusive mouse use caused the greatest amount of muscle fatigue; mixed mouse and keyboard use caused an intermediate level of fatigue; and exclusive keyboard use caused the lowest levels of muscle fatigue.

The different physiological responses of the muscle between keyboard and mouse use support previous epidemiological findings that mouse use has stronger association with MSDs than keyboard use. Although those studies assumed that the prolonged static muscle loads and wrist posture during mouse use may further increase risks of MSDs, there has been lack of objective physiological measurements showing differences in physiological responses between mouse and keyboard use. Therefore, this study supplies physiological evidence which corroborates the different associations with MSDs between keyboard and mouse use.

Although changes in keystroke durations often reflected the objective changes in muscle twitch contraction durations, the changes in mouse button-click durations did not have as strong as an association. Therefore, in order to consider keystroke and mouse click durations as a surrogate measure of involuntary contraction durations, future studies should also take extensors into account. Of course, central components from brain to motor neurons would have contributed those discrepancies as well.

The study results indicated that electrical stimulation of the muscle had the sensitivity to measure muscle fatigue resulting from computer work and was able to characterize different levels of muscle fatigue between the three different modes of computer use evaluated. Given the lack of sensitivity of other assessment tools, electrical stimulation of the muscle appears to be a viable method for objectively measuring muscle fatigue resulting from low intensity work.

Outcomes/Relevance/Impact:

The primary outcome of this study is the potential to use the subject's own mouse and keyboard as and exposure assessment device; however, further research is needed to assess and refine the method. If systematic changes in keystroke durations indicate muscle fatigue and are a precursor to more severe computer related injuries, then the operator's own computer could monitor the keystroke duration and proactively notify the user that they may benefit from a change in activities, thereby potentially reducing the operator's subsequent chances for developing a computer-related musculoskeletal disorder. Furthermore, since the keystroke duration can be readily and non-invasively measured by software program installed on the user's computer, it has potential to be used as a non-invasive, cost-effective assessment measure of muscle fatigue for large epidemiological studies.

The study also demonstrated that the mouse use resulted in more severe muscle fatigue than the keyboard use, and if muscle fatigue is indicative of the risk of injury, keyboard use should be less harmful than mouse use. These findings should help companies who employ computer workers to assess the potential risk for injury based on how individual employees use their computer. In addition, these findings may guide companies on how to design their computer-based work to reduce employees' risk of injury.

Scientific Report:

Pre-AIM Final Progress – validating a computer monitoring program

In addition to the two major aims stated in the grant, *we* validated that the CMP provides accurate measures of keystroke durations, sensitivity to capture small subtle changes in the durations, and robustness of these measures to differences on keyswitch designs. Through repeated measures design, we compared software-based keystroke durations to hardware-based keystroke durations (gold standard) to verify the accuracy and sensitivity of the duration measures. Furthermore, we used a force platform to measure the keystroke durations (gold standard) which is independent of keyswitch designs and compared them to software measured keystroke durations in order to determine whether the software-based keystroke durations are robust measures of keystroke durations.

Validating the accuracy and sensitivity of Computer Monitoring Program.

Background:
Some previous studies have used software programs to measure keystroke and mouse button-click durations. However, the accuracy of these software programs has never undergone rigorous validation and may be computer and/or dependent on the Operating Systems (OS). Some studies have verified the performance of these OS-dependent software programs; however, these studies only validated the software's performance for measuring the total duration of computer use or the cumulative number of pointing device related activities, not keystroke or mouse button-click durations. Therefore, our goal is to assess the accuracy and sensitivity of a software program for measuring keystroke durations.

Methods:
The experiment was a repeated measures design where the keystroke durations were measured from each subject for 2 minutes at eight time periods, with 75 minutes between each typing session, spanning an 8 hour day. During the typing tasks, keystroke durations were measured by both an external USB logger (gold standard) and our CMP. The USB logger-based keystroke durations then served as the reference and were compared with the CMP-based keystroke durations. The major difference between systems was the CPM was subject to program specific delays, plus any potential delays associated with the probabilistic operation of the Windows Operating System, which could be up to 20 ms. In comparison, the external USB logger was not affected by OS, other software programs, or delays since it registered all the digital signals directly from keyboard.

Results:
The keystroke durations measured by the CMP underestimated by about 4 milliseconds (ms) as compared to those measured by the external logger. Despite the underestimation, however, the software-based measures were almost perfectly correlated with the logger-based measures (Figure 1(a)). Furthermore, time-dependent variability in keystroke durations was consistent between the two different measures (Figure 1(b)); that is, small time-dependent differences in keystroke durations among the measurement times captured by the USB logger was matched to those measured by the CMP.

Discussion:
In conclusion, the CMP appears to have the sensitivity and accuracy for detecting small subject- and time-dependent changes in keystroke durations and therefore, may be a viable exposure assessment tool for using changes in keystroke durations to proactively detect when computer operators may be developing muscle fatigue. Since the software program can be readily distributed and installed in computer user's computers, its benefits would be the simplicity, low cost and ability to collect large samples for epidemiological purposes.

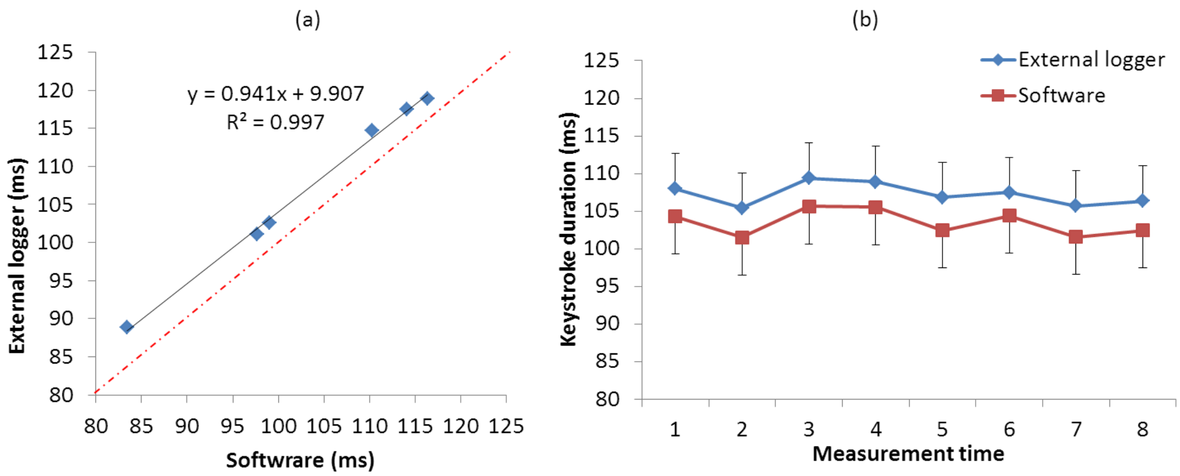

Figure 1 Comparisons between CMP-based and USB-based keystroke durations: (a) correlation between the two measures; (b) the differences in keystroke durations between the two measures across the eight measurement times. The dotted lines are the ideal identity lines. [n=6]

Validating robustness of CMP-based keystroke durations to differences in keyswitch designs.

Background: An exposure-response relationship has been shown between muscle fatigue and systematic changes in keystroke durations. Since keystroke durations can readily be measured by the CMP, CMP has potential as a large scale, non-invasive exposure assessment tool. However, the CMP-based keystroke durations may be adversely affected by the differing keyswitch force-displacement characteristics that exist across desktop and laptop keyboards. Thus, our goal was to determine if the CMP-based keystroke durations are robust to differences in keyswitch designs.

Methods: The experimental task consisted of having subjects type for 15 minutes each on three keyboards, which have different keyswitch force-displacement characteristics, mounted on top of a thin force platform. During the typing tasks, the keystroke durations were collected from both the force platform and CPM. Since force-based keystroke durations are not affected by differences in keyswitch force-displacement characteristics, it served as the reference and were compared with the CMP-based keystroke durations.

Results: The CMP-based keystroke durations had greater differences across keyboards than the force-based measures. Despite the significant differences between the two measures, the

CMP-based keystroke durations were highly correlated with the force-based measures (figure 2).

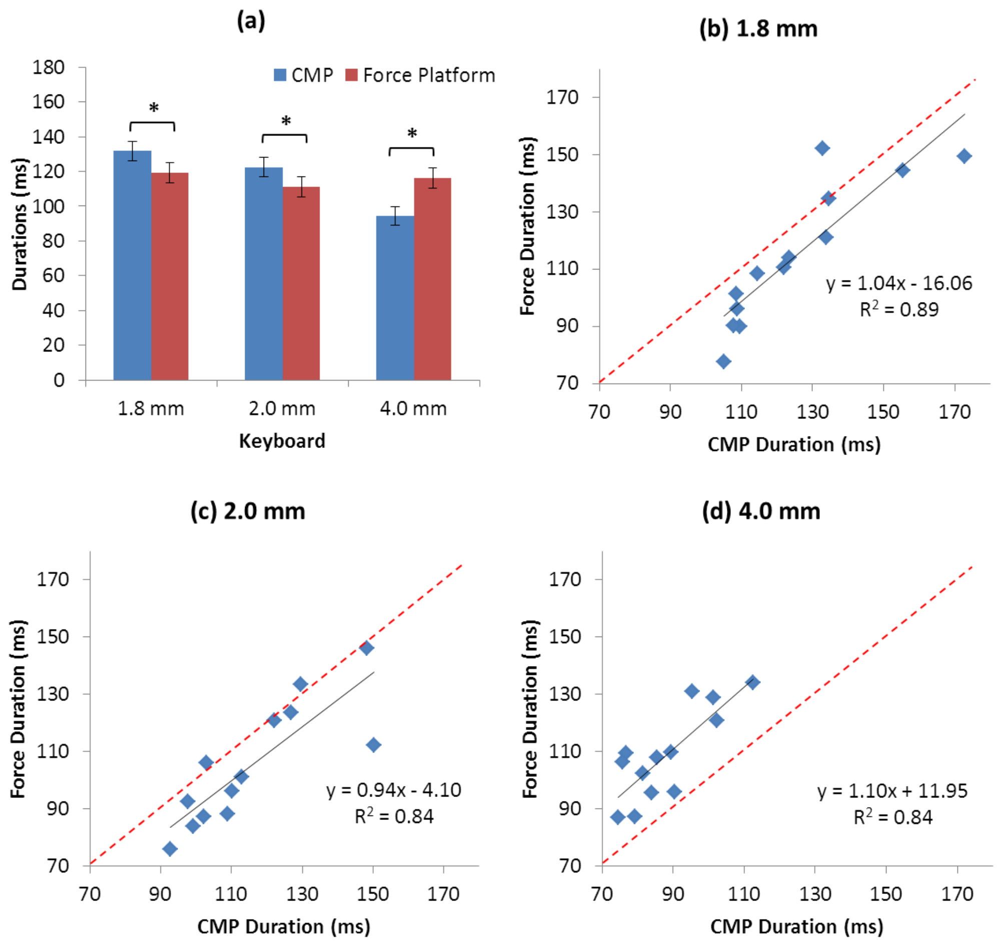

*Figure 2: (a) Comparisons of CMP- and force-based keystroke durations; (b-d) Linear fits and correlations between the two measures for (b) 1.8 mm, (c) 2.0 mm and (d) 4.0 mm travel keyboards, respectively. The * denotes statistical significance. The dotted lines are the ideal identity lines.*

Discussion:

Although the keystroke durations measured by the CMP depend on the force-displacement characteristics of the keyboard, the high correlation between the two measures indicates that the CMP-based keystroke durations approximate the true force-derived keystroke durations independent of the keyswitch force-displacement characteristics. Therefore, for large-scale field studies, the CMP-based keystroke durations, which can be readily measured by the CMP installed on users' computers, can be used as surrogate, non-invasive force duration measures in lieu of the more complicated, expensive, and invasive force platform-derived measurements.

Aim 0 Final Progress: determining whether muscle twitch force and duration are relatively stable under the control condition; if they are stable, whether no change is also found in other measures including keystroke, mouse button-click, and finger tapping durations.

Background

A control condition was administered to obtain baseline measures in order to determine whether our measurements were stable with no exposure to computer work and whether the responses in the control condition were different to the three exposure conditions (keyboard use, mouse use, and the combined keyboard and mouse use) . This control condition allowed us to account for the natural variability in the physiological state of the finger flexor muscle without computer use. In addition, the control condition enabled us to determine whether the electrical stimulation or testing method itself caused temporal changes in any of our dependent measures.

Methods

Eighteen subjects (9 females and 9 males) were not allowed to perform any computer-related activities in control condition. To compare the baseline measures against the measures obtained from the three exposure conditions, the muscle's twitch force response to electrical stimulation was collected (involuntary muscle contractions), subjects performed a series of finger taps against a force transducer (voluntary muscle contractions), standardized typing and mousing tasks were administered and subjective central and peripheral fatigue ratings were collected At 0, 75, 165, 270, 360, 390, 420, 480 min.

Result

In the control condition (Figure 3(a)), FDS muscle twitch forces increased by 10% relative to the initial, baseline measures whereas the twitch durations (contraction time + ½ relaxation time) were relatively stable. Keystroke and voluntary contraction (finger tapping) durations did not vary over the seven time periods, compared to their initial measures, whereas the mouse button-click duration systematically shortened over time. Subjective fatigue measures in the hand, wrist, forearm, shoulder, and neck did not differ from their initial responses whereas subjective central fatigue measured at measurement 480min was higher than its initial value (Figure 3(b)).

Discussion

As expected, involuntary (twitch), voluntary (finger tapping), and keystroke durations did not change over time in the control condition because there was no physical exposure to fatigue the muscle. However, the twitch force increased by 10% of its baseline measure. This increase in muscle twitch force may be related to a slight increase in body temperature across the day. Another possible cause is that the repeated electrical stimulation of the muscle may induce muscle potentiation – a slight increase in the force response of the muscle to electrical stimulation over time (Chang et al., 2009; Peter Wallace Johnson, 1998; MacIntosh et al., 2006).

Although there was a lack in the contraction duration of the muscle in response to electrical stimulation, mouse button-click duration systematically shortened throughout the day. This may be due to learning effects with the simulated mouse point-and-click task used to collect mouse button-click durations. The targets were highlighted sequentially, so participants were able to predict where the next target will be and accordingly prepare the next movements to click the following targets. In future studies, it may be beneficial to randomize the order with which the targets appears or craft a more realistic mouse task in order to determine whether changes in the mouse button-click duration mirror those in the twitch duration.

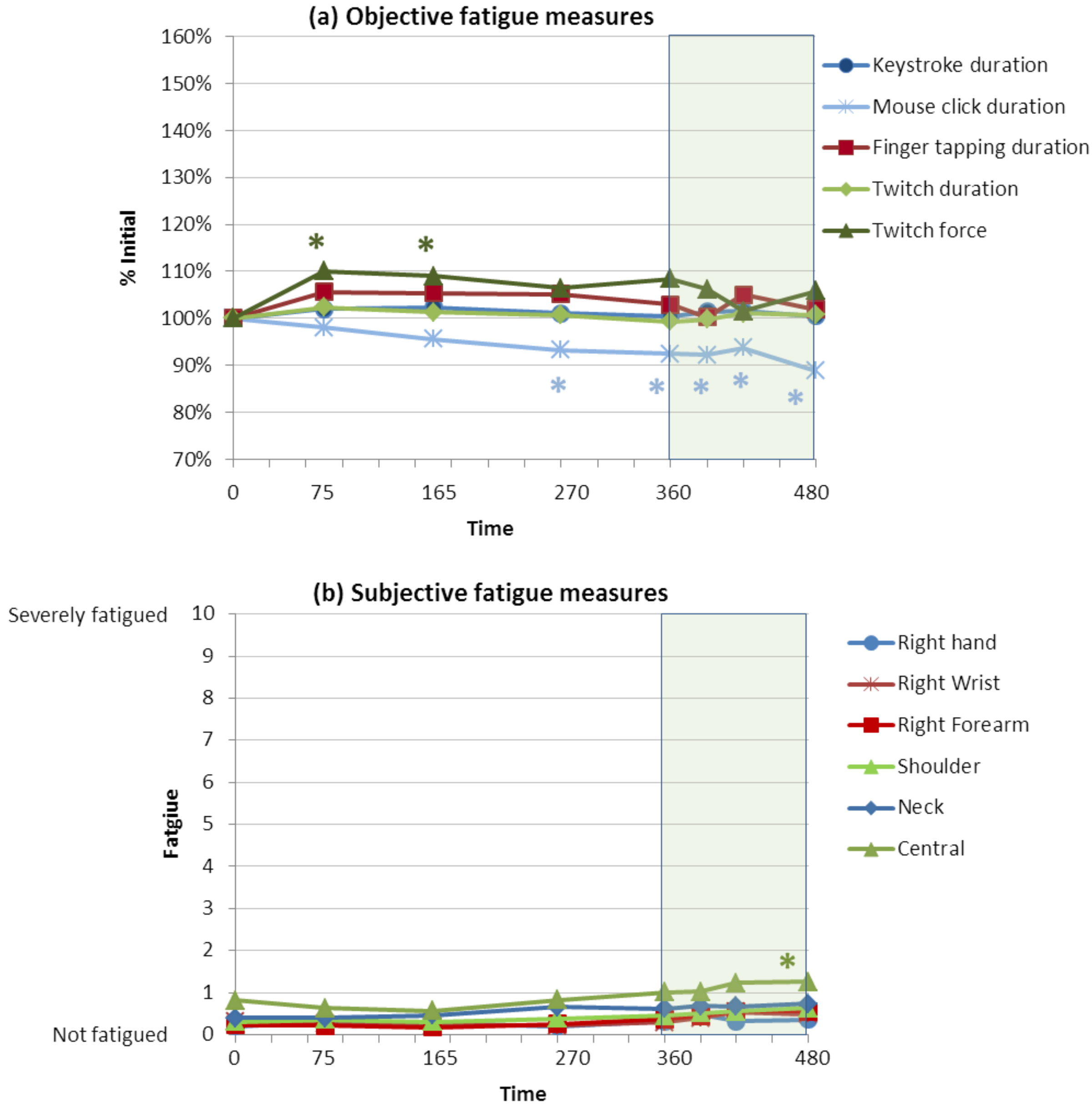

*Figure 3. Changes in the various dependent measures in the control condition [n=18]. (a) objective measures including changes in keystroke, mouse button-click, voluntary contraction (finger tapping), and involuntary contraction (twitch) durations including twitch forces; all the values normalized by the initial values at time 0. (b) subjective measures including peripheral and central fatigue. The * denotes statistical significance, standard error bars omitted for clarity.*

Aim 1 Final Progress: determining whether there are systematic changes in keystroke durations which parallels muscle fatigue measured with electrical stimulation of muscle

The first aim as stated in the grant is to determine whether there is a systematic changes in keystroke or mouse button-click duration with six hours of intensive keyboard use and whether the changes in keystroke or mouse button click duration parallels objective voluntary and involuntary changes in the physiological state of the muscle measured during voluntary (a standardized typing, mousing and finger tapping test) and involuntary (electrical stimulation of the muscle - low frequency fatigue and muscle contraction and one-half relaxation times) activities..

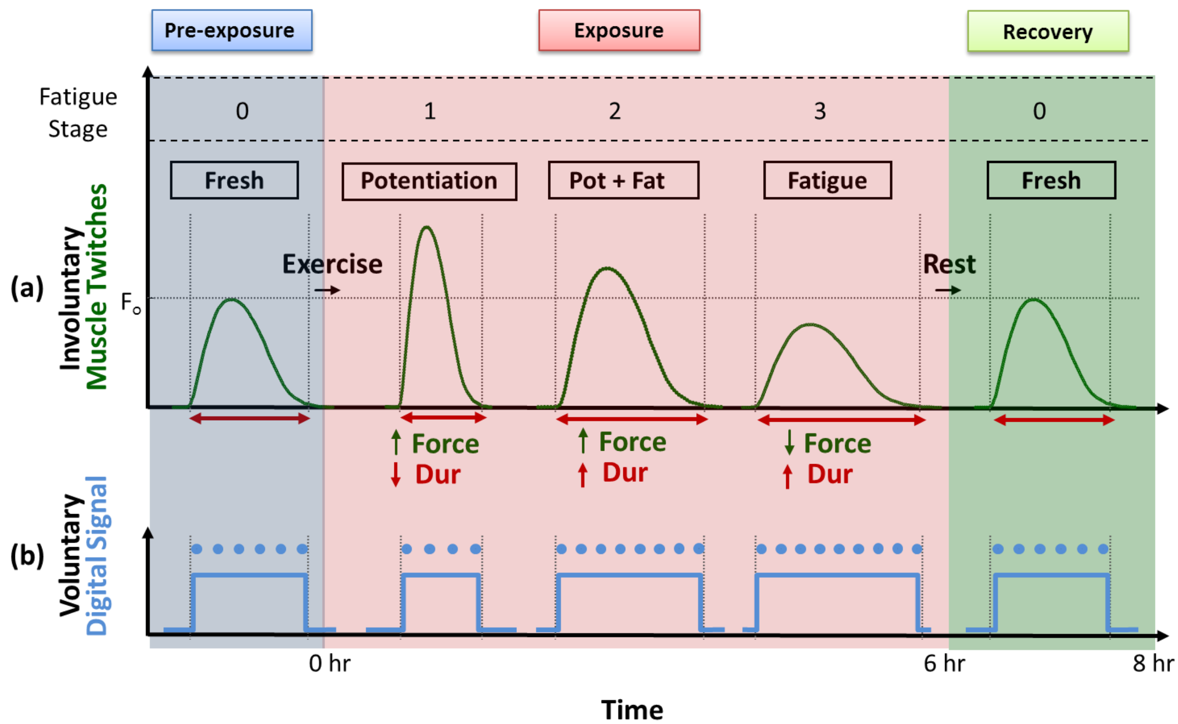

Figure 4. Schematic representation of muscle fatigue (a): fresh (0), potentiated (1), potentiated and fatigued (3) and fatigued (4) muscle twitch. The corresponding digital signals measured from the mouse button or keyboard presented to visualize the hypothesis (b).

Background

Although the exact underlying mechanisms associated with computer use and MSDs are not well understood, the MSDs are assumed to develop from the accumulation of micro trauma over moderate to long periods of time. Therefore, early detection of physiological degradation (i.e. muscle fatigue) may help reduce the occurrence of MSDs. There are several laboratory-based assessment tools to measure muscle fatigue; however, due to their invasiveness, insensitivity to low-level fatigue, lack of portability and cost, these measurement tools may not be appropriate for measuring computer-related muscle fatigue in field-based or occupational settings. A dearth of appropriate assessment tools has made it difficult to establish rigorous exposure-response relationships. We completed a repeated-measures study to determine whether there were temporal physiological changes in the muscle's force response (Figure 4a), whether there were corresponding temporal changes in the digital duration of keyboard and mouse button click durations (Figure 4b) and whether the subject's own keyboard and mouse (by measuring changes in keystroke and/or mousebutton-click durations) could be used as a surrogate, non-invasive cost-effective exposure assessment tool to proactively detect when computer operators may be developing muscle fatigue, proactively notify them of their fatigue, and thereby reduces their subsequent chances of developing a computer related musculoskeletal disorder.

Methods

Eighteen subjects (9 male, 9 female) were asked to type chapters of Grimm's Fairy Tale for 75 minutes at their normal typing speed four times (Figure 5). All participants were given the same chapters but the order of chapters was randomized in order to minimize any confounding effects. This 6-hour intensive typing task was considered to be intensive enough to induce muscle fatigue. Before typing (0 min), during typing (75, 165, 270, 360 min) and in two hours of recovery (390, 420, 480 min), the muscle's twitch force response to electrical stimulation was collected (involuntary muscle contractions), subjects performed a series of finger taps against a force transducer (voluntary muscle contractions), standardized typing and mousing tasks were administered, and subjective central and peripheral fatigue ratings were collected using LabView-based programs. Before, during and after the typing task the keystroke durations, mouse button-click durations, voluntary and voluntary muscle contractions, and subjective and central fatigue scores were measured and compared.

Results

During intensive keyboard use, twitch force systematically increased approximately 25 to 30% while twitch durations (contraction time + ½ relaxation time) systematically decreased up to 3% (Figure 5(a)). During the 2 hours of recovery, the twitch force and twitch contraction duration returned to pre-exposure, baseline levels. Mouse button-click durations and voluntary muscle contraction durations (finger tapping durations) did not show any significant changes during or after the intensive keyboard typing.

Subjective peripheral fatigue measures in hand, wrist, forearm, shoulder, and neck significantly increased over time during the typing task and decreased during the two hours of recovery after typing (Figure 5(b)). Although the subjective levels of peripheral fatigue decreased in the recovery period, they remained elevated and significantly higher than the pre-exposure, baseline measures. Central fatigue measures mirrored the peripheral fatigue measures.

Discussion

The increase in twitch forces and decrease in twitch durations indicated that the intensive keyboard use resulted in early-stage of muscle. As described in Figure 4, early-stage muscle fatigue (Stage 1) is characterized by increased twitch force and shortened twitch durations.

Although changes in twitch durations were statistically significant, these changes were small representing only a 3% change/shortening in the muscle contraction duration. This finding is consistent with the previous studies (Chang et al, 2009; Johnson 1998). These small changes in twitch durations may indicate early fatigue-related changes in physiological status of the muscle.

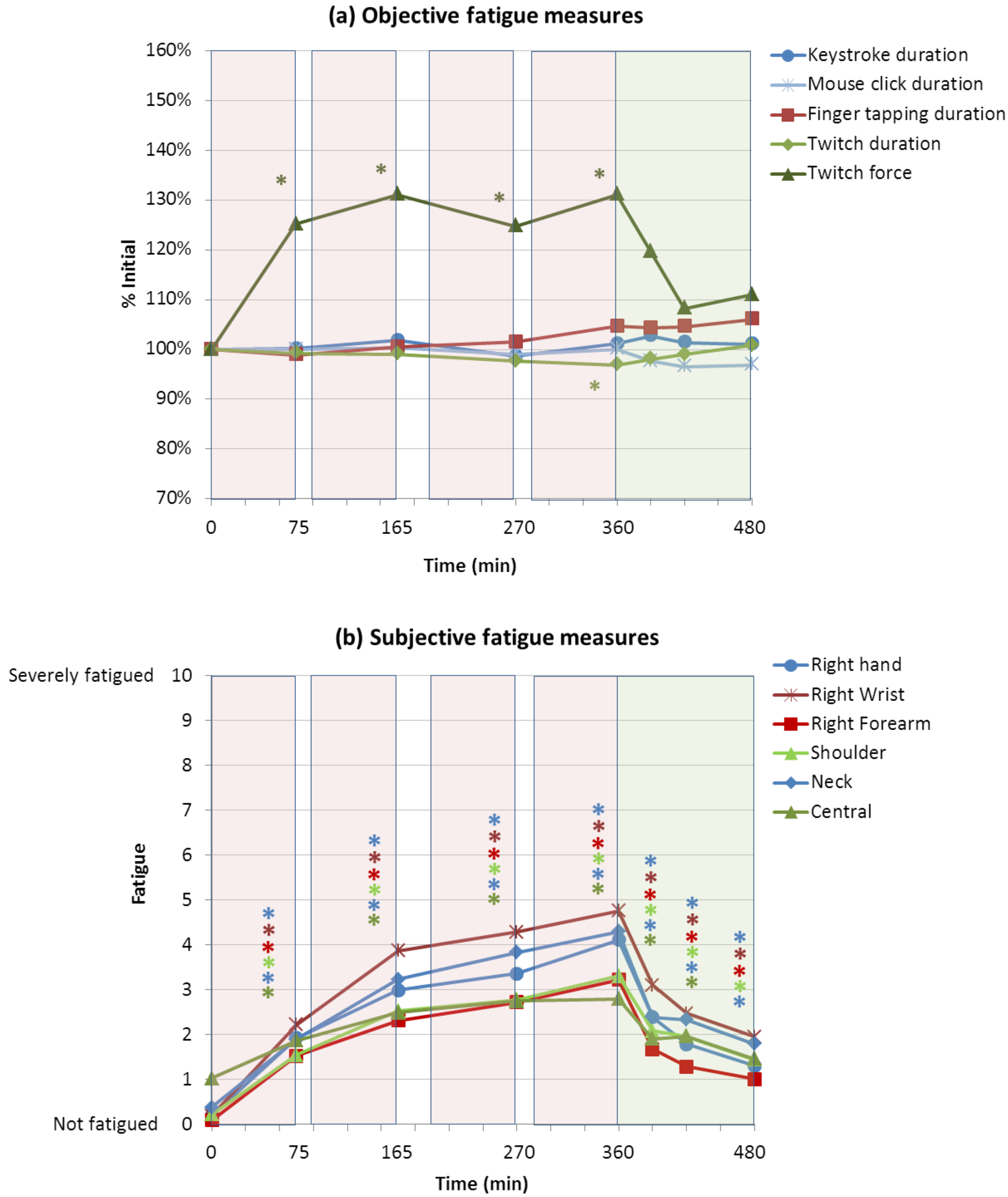

*Figure 5. Changes in the various dependent measures in the keyboard condition [n=18]. Shaded columns (red) indicate 75-minute blocks of exposure time (keyboard use), the rest breaks between the blocks were 15, 30, and 15 minutes long respectively, including two hours of recovery (green) at the end after keyboard use had ceased. (a) objective measures including changes in keystroke, mouse button-click, voluntary contraction (finger tapping), and involuntary contraction (twitch) durations including twitch forces; all the values normalized by the initial values at time 0. (b) subjective measures including peripheral and central fatigue. The * denotes statistical significance, standard error bars omitted for clarity.*

The twitch duration was measured from the involuntary contraction evoked by electrical stimulation on the FDS muscle bypassing the central nerve system. In contrast, the keystroke, mouse button-click, and finger tapping durations were measured from the voluntary finger movement which is likely to be affected by peripheral and central components as well as other muscles such as finger extensors. Numerous studies have shown the potential differences between the voluntary and involuntary contraction. Due to these very small changes in muscle contraction durations, capturing these small durational changes in keystroke, mouse button-click, and/or finger tapping durations may be difficult.

Although the muscle twitch responses showed that intensive keyboard use resulted in early-stage muscle fatigue, subjective peripheral fatigue measures substantially increased over time due to the keyboard use (Figure 5(b)). Previous studies have shown that the subjective sense of peripheral fatigue is not necessarily synchronized with objective measures of muscle fatigue.

Aim 2 Final Progress: determining whether there are systematic changes in mouse button-click durations which parallels muscle fatigue measured with electrical stimulation of muscle

The second aim as stated in the grant is to determine whether there is a systematic changes in keystroke or mouse button click duration with six hours of intensive mouse and whether the changes in keystroke or mouse button click duration parallels objective voluntary and involuntary changes in the physiological state of the muscle measured during voluntary (a standardized typing, mousing and finger tapping test) and involuntary (electrical stimulation of the muscle - low frequency fatigue and muscle contraction and one-half relaxation times) activities..

Background

Computer use has long been associated with MSDs. Previous epidemiological studies have shown that mouse use has stronger association with musculoskeletal symptoms and/or injuries than keyboard use. Therefore, it would be worthwhile to investigate whether intensive mouse use results in greater changes in the physiological state of the muscle (i.e. muscle fatigue) compared to intensive keyboard use. If there are greater physiological changes with computer mouse use, then this will corroborate finding in the computer workforce which shows a greater number and proportion of computer-related injuries are associated with computer mouse use. Furthermore, if there are greater physiological changes in the muscle associated with intensive computer mouse use, we would like to determine whether those changes can be captured by either changes in keystroke or mouse button click durations.

Methods

Eighteen subjects (9 male, 9 female) were asked to play the computer card game Solitaire for four 75-minute blocks (Figure 6). The computer card game *Solitaire* was chosen to strike a balance between boredom and providing a standardized mousing task for the subjects to perform. This 6-hour intensive mousing task was considered to be intensive enough to induce muscle fatigue. Before mouse use (0 min), during mouse use (75, 165, 270, 360 min) and in two hours of recovery (390, 420, 480 min), the muscle's twitch force response to electrical stimulation was collected (involuntary muscle contractions), subjects performed a series of finger taps against a force transducer (voluntary muscle contractions), standardized typing and mousing tasks were administered, and subjective central and peripheral fatigue ratings were collected using LabView-based programs. Before, during and after the mousing task the keystroke durations, mouse button-click durations, voluntary and voluntary muscle contractions, and subjective and central fatigue scores were measured and compared.

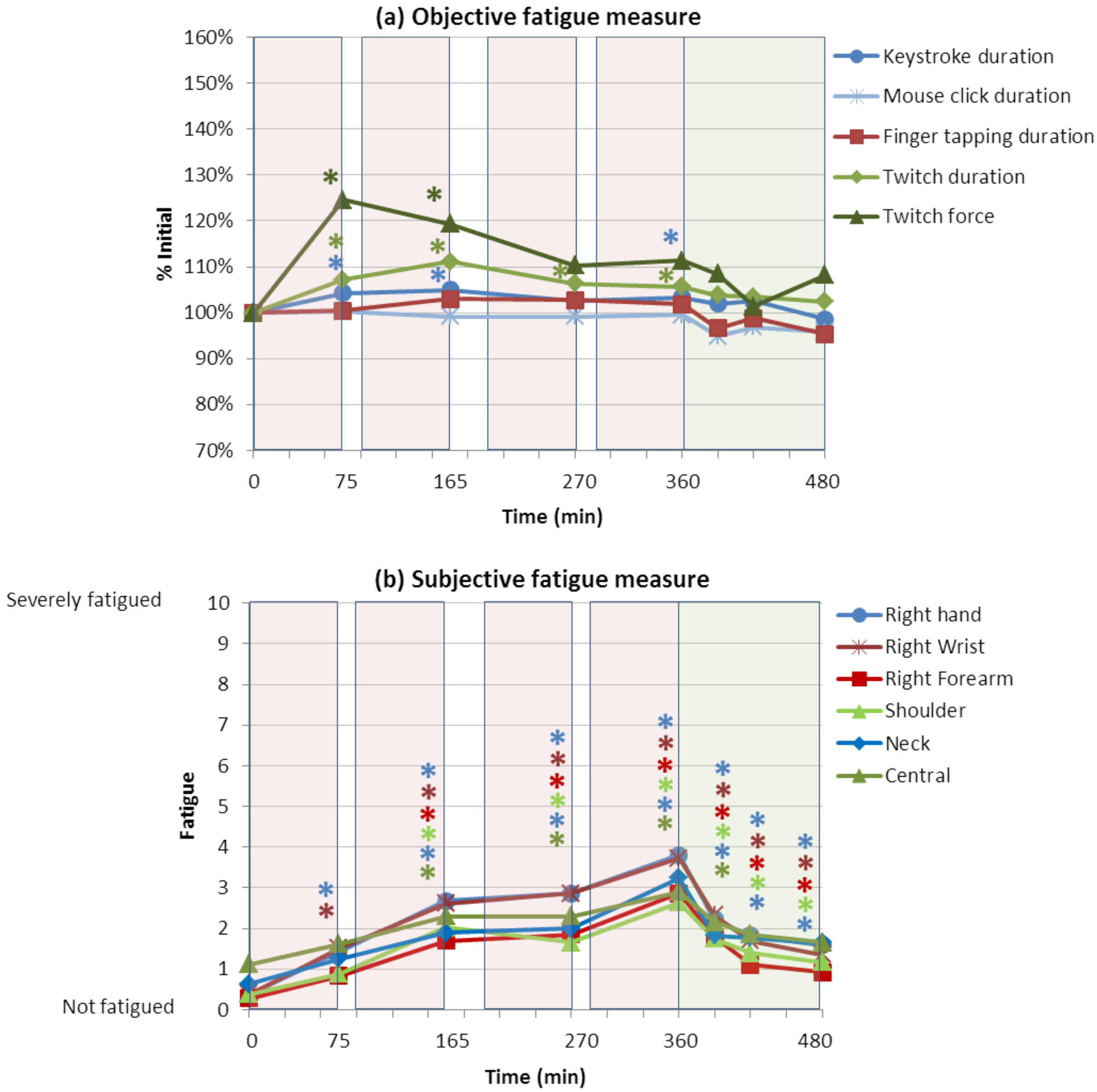

*Figure 6: Changes in the various dependent measures in the mouse condition [n=18]. Shaded columns (red) indicate 75-minute blocks of exposure time (mouse use), the rest breaks between the blocks were 15, 30, and 15 minutes long respectively, including two hours of recovery (green) at the end after mouse use had ceased. (a) objective measures including changes in keystroke, mouse button-click, voluntary contraction (finger tapping), and involuntary contraction (twitch) durations including twitch forces; all the values normalized by the initial values at time 0. (b) subjective measures including peripheral and central fatigue. The * denotes statistical significance, standard error bars omitted for clarity.*

Results
The results indicated that the six hours of intensive mouse use caused more severe muscle fatigue than the six hours of intensive keyboard use. During the first 75-minutes of intensive mouse, twitch forces systematically increased 25% and then gradually decreased over time (Figure 6(a)). In contrast to the intensive typing task, the twitch duration lengthened by 10% (rather than shortening 3%) and remained lengthened during the 6-hour exposure period, then returned towards pre-exposure, baseline levels during the 2-hours of recovery. The keystroke durations were significantly longer than initial measure in three out of the four measurements during intensive mouse use and then returned towards pre-exposure, baseline levels during the 2-hours of recovery. The mouse button-click duration and finger tapping durations did not systematically change during intensive mouse use and in the two hours of recovery.

The subjective peripheral fatigue measures in hand, wrist, forearm, shoulder, and neck systematically increased during the 6-hours of intensive mouse use and decreased during the 2-hour recovery period (Figure 6(b)). Although the subjective levels of peripheral fatigue decreased in the recovery period, they remained elevated and significantly higher than the pre-exposure, baseline measures. Central fatigue measures mirrored the peripheral fatigue measures.

Discussion
After the first 75-minutes of intensive mouse use, both twitch force and twitch duration significantly increased, indicating a more severe level of early-stage muscle fatigue relative to the muscle fatigue measured in the keyboard condition. As described in Figure 4, this more severe early early-stage muscle fatigue (Stage 2) is characterized by increased twitch force and increased twitch durations. In the 3 remaining block of intensive mouse use (Figure 6(a)), the twitch forces systematically decreased over time while the lengthened twitch duration was sustained during the 6-hour exposure periods. This finding demonstrated that the physiological state of the muscle was transitioning from potentiation to a state of potentiation and fatigue.

The increase in keystroke duration during mouse use paralleled the increases in muscle twitch duration. Despite the inherent differences between the voluntary and involuntary contractions, the keystroke duration appears to have mirrored the physiological changes in the muscle. This finding is consistent with a previous study (Chang et al., 2009) which found changes in keystroke duration after fatiguing, intensive exercise paralleled the temporal changes in muscle twitch durations. This implies that the keystroke duration may be able to detect muscle fatigue and therefore could be used as a non-invasive, cost-effective assessment tool to measure muscle fatigue during computer use. However, mouse button-click durations did not reflect the temporal, fatigue-related changes in muscle twitch durations. It is unclear as to while there where changes in keystroke duration, but not a parallel change in muscle button click durations. Perhaps it has to do with the biomechanical difference between a ballistic keystroke and a ballistic mouse button click.

The results showed that the changes in twitch force and twitch duration during mouse use were different from those during keyboard use. The twitch data showed that intensive keyboard use resulted in the early-stage muscle fatigue (Stage 1, potentiation) whereas the intensive mouse use induced a more severe state of early-stage muscle fatigue (Stage 2, combined fatigue and potentiation). Since all the measures were relatively stable in the control condition, the temporal changes observed during keyboard and mouse use were the result of the intensive use of the computer input device. The different physiological responses to keyboard and mouse use support previous study findings that the mouse use is more strongly associated with MSDs, compared to keyboard use. Although those studies have argued that prolonged static loading and longer usage duration may increase the association between mouse use and MSDs, there has been lack of physiological evidence to objectively document the difference between mouse and keyboard use. The results of this study provide physiological evidence that corroborates the greater number and proportion of injuries associated with mouse rather than keyboard use.

Aim 3 Final Progress: determining whether combined mouse and keyboard work cause temporal changes in keystroke and/or mouse button-click duration and parallels objective measures of muscle fatigue.

In addition to Aim 1 and 2, we also investigated whether the six hours of combined mouse and keyboard use would result in muscle fatigue and whether the temporal changes in keystroke and/or mouse button-click durations paralleled the temporal physiological changes in the muscle's force response to electrical stimulation.

Background

The two conditions described in Aim 1 and 2 allowed us to investigate whether intensive keyboard and/or mouse use was associated with muscle fatigue. However, those conditions may not accurately represent realistic computer use since both the keyboard and mouse are used in normal computer operations. Therefore, it would be worthwhile to investigate whether combined intensive keyboard and mouse use results in muscle fatigue and whether the muscle fatigue is reflected by systematic temporal changes in keystroke and/or mouse button-click duration.

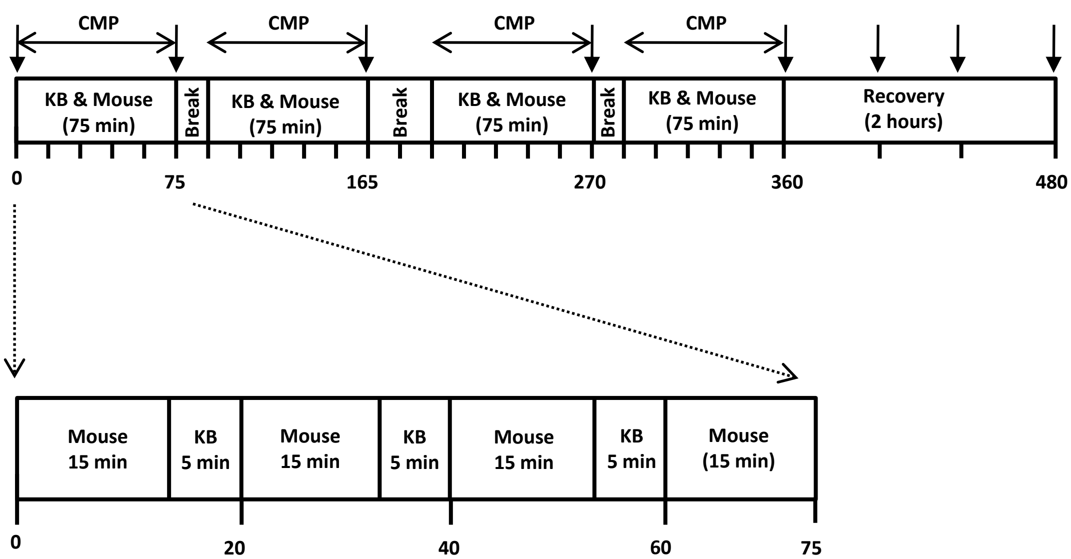

Figure 7. Design of combined mouse and keyboard task.

Methods

As shown in Figure 7, the same 18 subjects (9 male, 9 female) were asked to alternatively play the computer card game Solitaire for 15 minutes and type for 5 minutes during four, 75 minutes blocks. This combined 6-hour mouse and keyboard task was considered to be intensive enough to induce muscle fatigue. Before mouse and keyboard use (0 min), during mouse and keyboard use (75, 165, 270, 360 min) and in two hours of recovery (390, 420, 480 min) the

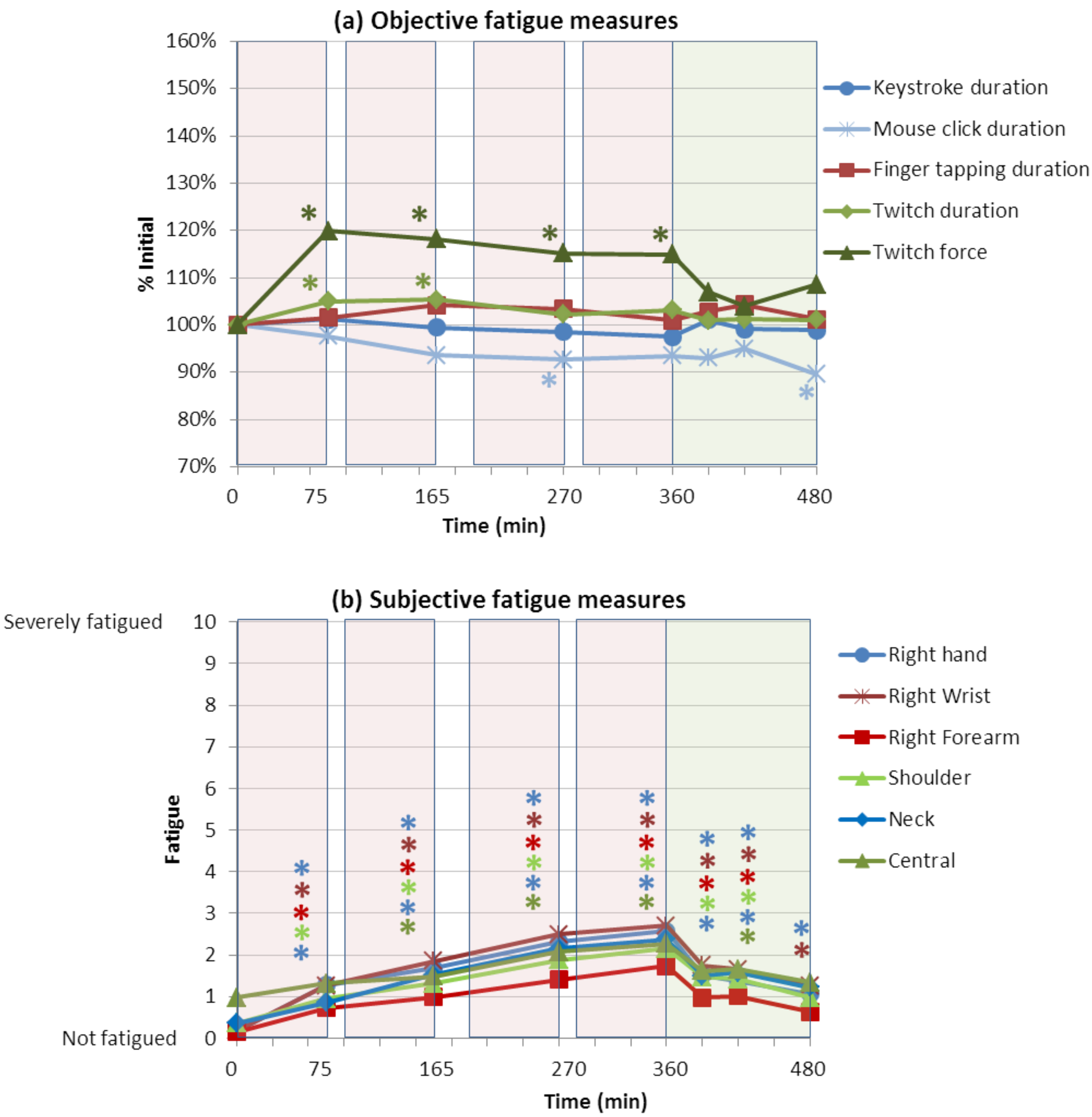

*Figure 8: Changes in the various dependent measures in the combined mouse and keyboard use condition [n=18]. Shaded columns (red) indicate 75-minute blocks of exposure time (mouse and keyboard use), the rest breaks between the blocks were 15, 30, and 15 minutes long respectively, including two hours of recovery (green) at the end after keyboard use had ceased. (a) objective measures including changes in keystroke, mouse button-click, voluntary contraction (finger tapping), and involuntary contraction (twitch) durations including twitch forces; all the values normalized by the initial values at time 0. (b) subjective measures including peripheral and central fatigue. The * denotes statistical significance, standard error bars omitted for clarity.*

muscle's twitch force response to electrical stimulation was collected (involuntary muscle contractions), subjects performed a series of finger taps against a force transducer (voluntary muscle contractions), standardized typing and mousing tasks were administered and subjective central and peripheral fatigue ratings were collected using LabView-based programs. Before, during and after the mousing and keyboarding task the keystroke durations, mouse button-click durations, voluntary and voluntary muscle contractions, and subjective and central fatigue scores were measured and compared.

Results

The twitch forces increased approximately 15~20% over the periods of using keyboard and mouse use; however, the force decreased to the baseline level during the recovery periods (Figure 8(a)). The twitch durations after the first two exposure sessions were significantly higher than its initial measure (p's < 0.01) whereas the other following twitch durations did not differ from the initial values. Keystroke and finger tapping durations did not show any significant changes in the keyboard and mouse use condition; however, the mouse button-click duration systematically shortened. Subjective peripheral and central fatigue significantly increased when using both the keyboard and mouse. Although subjective peripheral fatigue measures in most body regions returned to pre-exposure, baseline levels in the recovery period, the peripheral fatigue on the right hand and wrist persisted throughout recovery.

Discussion

In the combined intensive keyboard and mouse condition, muscle fatigue was between the early-stage fatigue measured during keyboard use (Stage 1, potentiation) and the intermediate-stage fatigue measured during mouse use (Stage 2, combined potentiation and fatigue). As observed in the keyboard condition (Figure 5), the twitch force significantly increased and remained continuously higher than its baseline measure during the exposure duration. Similar to the changes in the mouse condition, the twitch duration also increased in the combined keyboard and mouse condition. The magnitude and trend of changes in twitch forces and twitch durations (Figure 8(a)) indicated that the level of muscle fatigue was between early- (Stage 1) and intermediate-stage (Stage 2) muscle fatigue, observed in keyboard and mouse use, respectively.

The combined keyboard and mouse condition consisted of 60-minute mouse and 15-minute keyboard use. Although the majority of the exposure was computer mouse operation, the fatigue level was lower than the level observed during the exclusive mouse condition. This may be due to the variation of the tasks. Since monotonous and repetitive tasks are well-known risk factors for muscle fatigue and MSDs, task variation is thought to be an effective administrative ergonomic intervention. The mixture of two different tasks increased the task variability; and therefore, the more severe muscle fatigue that resulted from exclusive computer mouse use, was reduced.

Although the temporal changes in twitch durations were statistically significant, keystroke durations did not show any significant temporal changes in the combined keyboard and mouse condition. This may be due to relatively small changes/increase in twitch durations (up to 5%), compared to the larger changes/increase in twitch duration measured in mouse condition (up to 11%). As discussed earlier, keystroke durations may be able to detect the twitch duration changes when the twitch duration changes are reasonably large.

Despite the minimal changes in the twitch and keystroke durations, the mouse button-click duration systematically shortened over time (Figure 8(a)). Similar trends were observed in the control condition where subjects were not exposed to computer-related activity. As discussed earlier in the control condition, this may be due to limitations of the simulated pointing task used to collect mouse button-click durations where a learning effect over time may have been present.

Subjective peripheral and central fatigue significantly increased (Figure 8(b)). However, the level of the increased fatigue was lower than that observed in the other exposure conditions. Furthermore, most subjective fatigue measures in this condition recovered to the baseline level at the end of the experiment except for the right and wrist whereas most of them persisted throughout the recovery periods in the exclusive mouse and the exclusive keyboard conditions. This may again be explained by the variability created by alternating between using the mouse and the keyboard. Higher variability during the combined mouse and keyboard use condition may have reduced monotonousness and repetitiveness, while increasing the physiological variability associated with the task; consequently, the level of the subjective central and peripheral fatigue was lower, compared to the exclusive keyboard or mouse use conditions.

Study Conclusions

The study results indicated that electrical stimulation of the muscle had the sensitivity to measure muscle fatigue resulting from computer work and was able to characterize different levels of muscle fatigue between the three different modes of computer use evaluated. Given the lack of sensitivity of other assessment tools, electrical stimulation of the muscle appears to be a viable method for objectively measuring muscle fatigue resulting from low intensity work.

The muscle fatigue results indicated that exclusive mouse use caused the greatest amount of muscle fatigue; mixed mouse and keyboard use caused an intermediate level of fatigue; and exclusive keyboard use caused the lowest levels of muscle fatigue. The different physiological responses of the muscle between keyboard and mouse use support previous epidemiological findings that mouse use has stronger association with MSDs than keyboard use. Although those studies assumed that the prolonged static muscle loads and wrist posture during mouse use may further increase risks of MSDs, there has been lack of objective physiological measurements showing differences in physiological responses between mouse and keyboard use. Therefore, this study supplies physiological evidence which corroborates the different associations with MSDs between keyboard and mouse use.

The primary outcome of this study is the potential to use the subject’s own mouse and keyboard as and exposure assessment device; however, further research is needed to assess and refine the method. If systematic changes in keystroke durations indicate muscle fatigue and are a precursor to more severe computer related injuries, then the operator’s own computer could monitor the keystroke duration and proactively notify the user that they may benefit from a change in activities, thereby potentially reducing the operator’s subsequent chances for developing a computer-related musculoskeletal disorder. Furthermore, since the keystroke duration can be readily and non-invasively measured by software program installed on the user’s computer, it has potential to be used as a non-invasive, cost-effective assessment measure of muscle fatigue for large epidemiological studies. To validate using the subject’s own keyboard as an exposure assessment device to reduce an operator’s chances of developing a subsequent musculoskeletal disorder, different durations and intensities of keyboard work should best tested in controlled laboratory studies and then subsequent studies, adequately powered should be conducted in less controlled more realistic field settings. In addition, the cumulative effect of computer use and systematic changes in keystroke durations should be evaluated over longer periods of time (e.g. multiple days, weeks or months).

Publications.

Peer Reviewed Papers

1. Kim JH, Johnson PW. (accepted) Viability of Using Digital Signals from the keyboard to Capture Typing Force Exposures. *Ergonomics*
2. Kim JH, Johnson PW. (2012) Can Digital Signals from the Keyboard Capture Force Exposures during Typing? *Work* 4(2012) 2588-2590.

Peer Reviewed Papers in preparation

1. Kim JH, Johnson PW. Validation of a Software Program for Measuring Fatigue-Related Changes in Mouse Button Click and Keystroke Durations. Target Journal – International Journal of Industrial Ergonomics.
2. Johnson PW, Komandur S, Crenshaw A, Kim JH, Dennerlein J. Relationship between Mouse Button Actuation Forces, Click Duration and Muscle Twitch Contraction and One-half Relaxation Times. Target Journal - European Journal of Applied Physiology.
3. Johnson PW, Kim JH. Physiological variations between keyboard and mouse use. Target Journal - European Journal of Applied Physiology.

Other Scholarly Publications

1. Kim JH, Johnson PW. (2011) Validation of software-based measures of keystroke durations with external USB-based logger. 61st Annual Industrial Engineering Research Conference, Reno, NV.
2. Kim JH, Johnson PW. (2011) Validation of a Software Program for Measuring Fatigue-Related Changes in Keystroke Durations. 33rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Boston, MA.
3. Kim JH, Johnson PW. (2012) Can Digital Signals from the Keyboard Capture Force Exposures during Typing? 18th World Congress on Ergonomics, Recife, Brazil.

Other Non-referred Publications/Presentations

1. Kim JH, Johnson PW. (2011) Validation of UW/Harvard Computer Interaction Monitoring Software for Measuring Fatigue-Related Changes in Keystroke Durations. 23rd Annual Occupational, Environmental, and Public Health Conference, Blain, WA.
2. Kim JH, Johnson PW. (2011) Can Digital Signals from the Keyboard Capture Force Exposures during Typing? Northwest Biomechanics Symposium 2011, Vancouver, BC, Canada
3. Kim JH, Johnson PW. (2011) Computer Input Devices as a surrogate exposure assessment tool. Korean-American Engineers and Scientists Association Northwest Regional Conference 2011, San Jose, CA.