33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Validation of a Software Program for Measuring Fatigue-Related Changes in Keystroke Durations

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Abstract— **Intensive computer use has been associated with musculoskeletal disorders (MSDs). Although the underlying mechanisms are still not fully understood, muscle fatigue is thought to be a contributing factor. Previous studies have shown that keystroke durations are related to muscle twitch durations and may be used as a surrogate measure of muscle fatigue. Software tools have been developed to measure keystroke durations; however, the accuracy of these programs may be influenced by the computer and/or the operating system (OS). Keystrokes were collected from six subjects and analyzed to determine whether there were any differences in keystroke durations measured by an OS-dependant software program and keystrokes collected directly from the keyboard using a USB analyzer (gold standard). The results demonstrated that the OS-dependant software program underestimated keystroke durations by 3.8 ms (103.5 vs. 107.3 ms; $p < 0.0001$) but keystroke durations at the individual level were highly correlated between the two systems ($R^2 = 0.997$). Despite the small differences, the high correlation between systems indicated that the software program could be used to collect keystroke durations.**

I. Introduction

INTENSIVE computer use has been known to increase the risk of developing musculoskeletal disorders (MSDs) [1-4]. Physical or biomechanical risk factors for MSDs include force, repetition, posture and the duration and distribution of these exposures [5-7]. Previous studies have already shown that the rapid and repetitive finger movements during keyboard use and prolonged static muscle loading during mouse use are associated with upper extremity MSDs [5,8,9].

Since most work-related MSDs develop from the accumulation of micro trauma to the soft tissues (muscles, tendons, ligaments and nerves) over time [10], an early detection of physiological changes (i.e. muscle fatigue) may reduce a computer operator's chances for developing MSDs. In order to detect computer-related muscle fatigue in field settings, it is essential to have a reliable and non-invasive muscle fatigue assessment method. There are lab-based methods to measure muscle fatigue (electrical stimulation of the muscle, electromyography, mechanomyography, etc.); however, these methods may not be suitable in field-based studies due to invasiveness, portability and cost.

Chang et al., [11] found that keystroke duration changed in the presence of muscle fatigue and paralleled fatigue-related changes measured from muscle twitch durations in the finger flexor muscles. Komandur et al., [12] demonstrated that mouse click duration may also be a surrogate measure for finger flexor muscle twitch durations. In these studies, when a keyboard key or mouse button was pressed and released, the keystroke and mouse click durations were measured using software that measured the duration of the digital ON/OFF signal.

The accuracy of these software programs have never undergone rigorous validation and may be computer and/or dependant on the Operating Systems (OS). Some studies have verified the performance of these OS-dependent software programs [13, 14]; however, these studies only validated the software's performance for measuring the total duration of computer use [14] or the cumulative number of pointing device related activities [13], not keystroke or mouse button-click durations.

If changes in keystroke duration can be used as surrogate measure of muscle fatigue, we need to be sure that our software-based monitoring programs have the accuracy and sensitivity to measure and detect small differences in keystroke duration. Therefore, the present study was conducted to assess the accuracy and sensitivity of a software program for measuring keystroke durations and small differences in keystroke durations while subjects typed on the keyboard.

II. Method

A. Subjects

Though e-mail solicitations, a total of 6 subjects including 3 males and 3 females were recruited to participate in this experiment. All the participants were touch-typists without a history of upper extremity MSDs. The average typing speed was 62.5 (SD 14.2) words per minute (WPM), ranging from 45 to 85 WPM. The average age of the participants was 22 (SD 1.6) years old, ranging from 21 to 25 years. The experimental protocol was approved by the Human Subject Committee at the University of Washington, and all subjects provided their written informed consent before participating in the experiments.

Manuscript received March 07, 2012. This work was supported by the National Institute for Occupational Safety and Health under R21 Grant (OH009088-02) and Washington State Medical Aid and Accident Fund. Validation of a Software Program for Measuring Fatigue-Related Changes in Keystroke Durations.

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B. Experimental design

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. The subjects typed on a standard keyboard (model SK-8115; Dell Inc; Round Rock, TX) and were instructed to type at their own pace mimicking their actual typing habits. The workstation was adjusted based on subject's anthropometric data in accordance with ANSI/HFES 100-2007.

During the typing tasks, keystroke durations were measured by both an external USB logger (USB Explore 200 Professional Edition; Ellisys Inc; Geneva, Switzerland) and a keystroke monitoring program developed using LabView software (Version 7.1; National Instruments; Austin, TX, USA). The external logger collected keystroke durations with the precision of ± 16.67 nanoseconds and saved the keystroke duration data on a separate host computer. In parallel, the LabView-based keystroke monitoring program, installed in the subject's computer, registered keystrokes with a resolution of approximately ± 5 milliseconds (ms). As shown in Fig. 1, the major difference between systems was the LabView-based program 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.

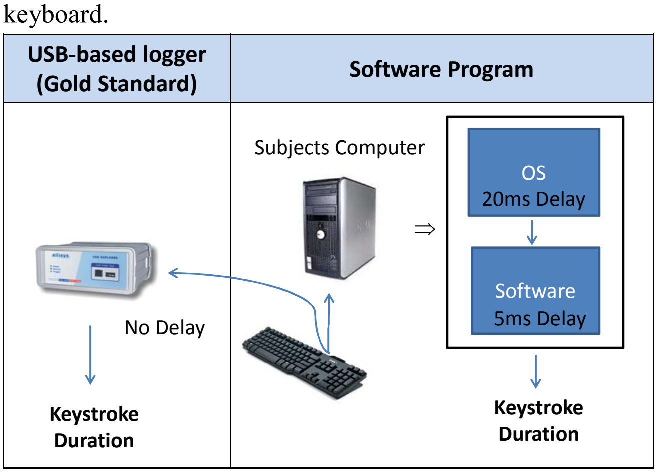

Fig. 1. The configuration of measurement systems including the external USB logger and software program.

C. Data analysis

Before analyzing the data, the individual keystroke data was screened to only include keystrokes associated with alphabetical keys, since other keys such as space, shift, control, alt numeric and functional keys might have different or non-ballistic key activations.

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 differences in keystroke durations measured by the external USB logger and the software program. In the model, the device, typing speed and measurement time were included as a fixed effect while subject was included as a random effect. Significance was noted when Type I error is less than 0.05.

III. Results

The external USB logger collected a total of 9,660 keystrokes from all the participants whereas the software-based program collected 9,638 keystrokes, a difference of 22 keystrokes or 0.22% of the total keystrokes collected. The keystroke durations measured by the software program were significantly shorter than those measured by the external logger (103.5 ± 5.04 vs. 107.3 ± 5.04 ms; $p < 0.0001$) (Fig. 2(a)).

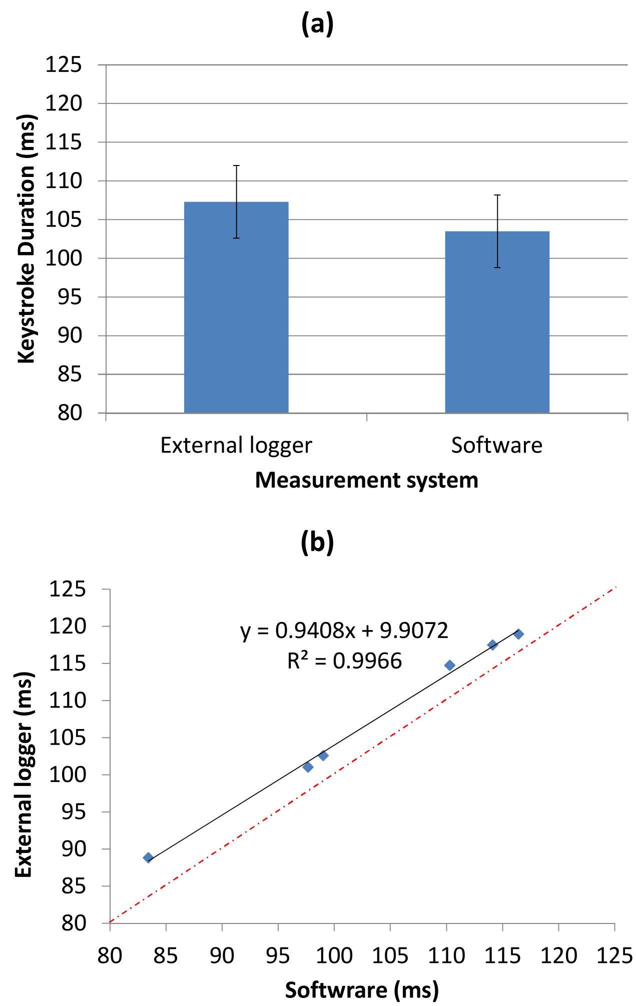

Fig. 2. The differences in keystroke durations between the external USB logger and software program: group level (a) and individual level (b).

The software-based measures were almost perfectly correlated with the logger-based measures (R^2=0.997). That is, these differences between two measurement tools were consistent at the individual level (Fig. 2(b)). The variation in keystroke durations of the software program was slightly larger than that of the external logger (SD: 37.7 vs. 34.6 ms).

The keystroke durations were not affected by typing speed ($p = 0.55$) and did not differ across the eight measurement time ($p = 0.63$). The interaction between the device and measurement time was not significant ($p = 0.99$), meaning that the keystroke durations measured by the software program were consistently shorter than those measured by the external logger (Fig. 3).

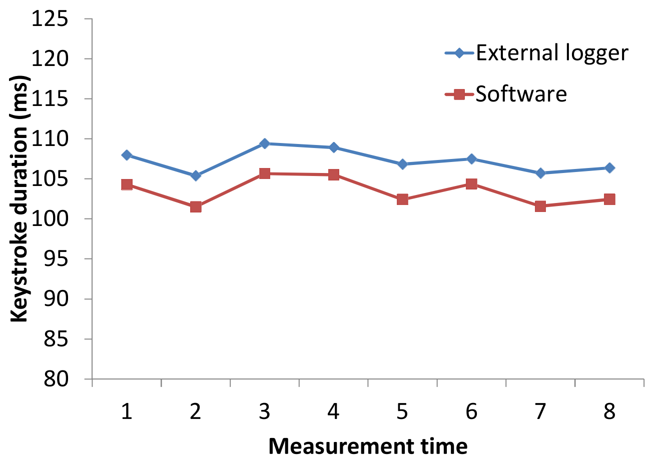

Fig. 3. The differences in keystroke durations between the external USB logger and software program across the eight measurement times. Standard errors omitted for clarity.

IV. Discussion

Since previous studies demonstrated that small, systematic changes keystroke durations occur as a muscle fatigues and recovers, the present study evaluated the sensitivity and accuracy of a software program for measuring keystroke durations. In order to use small, systematic changes in keystroke durations as a surrogate measure of muscle fatigue, the data collection tool must have the requisite sensitivity and accuracy. Therefore, we evaluated the sensitivity and accuracy of a software-based keystroke duration measurement program against an external USB logger which measured keystroke durations directly from the keyboards.

The results indicated that the software program underestimated keystroke durations by approximately 4 ms or 4% on average when compared to the external USB keystroke logger. Furthermore, the software program missed a small fraction (0.22%) of the total number of keystrokes. Although the keystroke durations measured by the systems were significantly different, these small differences may not be practically significant. As shown in Fig. 2(b), the correlation between the software- and logger-based measures was almost perfect (R^2=0.997), with the fitted line (with the slope of 0.94) very closely approximating the ideal identity line (the dotted line). Therefore, the keystroke durations measured by the software program appears to accurately predict the keystroke durations measured directly by the external USB logger.

In this small sample of subjects, typing speed was not associated with keystroke durations. We initially hypothesized that keystroke durations would decrease as typing speed increased, since more keystrokes would occur within a specific time (i.e. a minute). However, this trend was not observed in the current group of subjects.

The keystroke durations did not vary across the eight measurements. This result indicated that the study was appropriately designed to avoid any fatigue-related effects on keystroke durations. Despite the insignificant differences between the measurements, the software-based measures paralleled the logger-based measures (Figure 3). In other words, the software program was sensitive enough to detect the same small changes captured by the external USB logger.

Finally, as shown in Figure 2(b) where each point represents an individual subject, there were subject-dependant differences in keystroke durations. The high and nearly perfect correlation between the software program and the external USB logger indicated that the software program is sensitive enough to detect small, subject-dependent differences.

Although we assumed that the software program may depend on OS and computer processing power, the tests were only conducted on one computer. Therefore, future studies could investigate computers with different processing speeds and different variants of the Windows Operating Systems. Furthermore, since mouse click duration may also indicate muscle fatigue, it would be beneficial to evaluate the software program's sensitivity and accuracy for mouse button click durations.

In conclusion, our software program 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.

Acknowledgments

This study was supported by the National Institute for Occupational Safety and Health under an R21 Grant (OH009088-02) and Washington State Medical Aid and Accident Fund. The authors would also like to acknowledge the technical support of Patrik Rynell.

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