FINAL PROGRESS REPORT FOR R01 OH003997

Tools for exposure assessment of physical risk factors of VDT Workers

1 September 2005 to 31 August 2009.

PI: Jack Dennerlein, Ph.D.
Department of Environmental Health
Harvard School of Public Health
665 Huntington Avenue
Boston, MA 02115 USA
jax@hsph.harvard.edu
Tel 617 384 8812
Fax 617 384 8767

Co-Investigator: Peter Johnson, Ph.D.
Department of Environmental and Occupational Health Sciences,
University of Washington,
Seattle WA

Contents

Abstract 2
Scientific Report: 3
AIM 1 Final Progress – testing and validating a computer interaction monitor 3
Validating the Computer Interaction Monitor (CIM) Software Program (Primary Aim). 3
A Secondary Aim: Using the CIM to measure muscle fatigue due to computer usage. 4
Using the CIM to quantify associations of daily computer usage with daily musculoskeletal complains 5
Aim 2 Final Progress: Examining Sampling Strategies for physical risk factors 7
Pre - Aim 2 Hardware Development: Removing the vibration artifact from the typing force signal. 7
Aim 2: Evaluating various Sampling Strategies to assess the intensity measures of biomechanical factors (Primary Aim). 8
Aim 3: Effects of workstation set up on postural and force measurements 9
Publications. 12
Peer reviewed publications describing specific work completed in this study 12
Peer reviewed publications from studies supported by work completed in this study. 12
Selected conference papers, abstracts and publications 13

Abstract

In order to understand the high prevalence of work-related musculoskeletal disorders in the modern office, we aimed to develop specific exposure assessment tools and methods to measure physical risk factors of computer workers at their own workstations. Specifically, we pursued three goals. First, we validated a computer interaction monitor (CIM) software program in order to determine the optimal cutoff time that will capture both active interactions, such as measurable keyboard and pointing device events, and passive interactions, such as reading documents from the visual display terminal. Such CIMs provide detailed measurements of the frequency and duration of exposure. We monitored 20 individuals at their own workstations for four hours. During this time we recorded their computer interactions with both a CIM program installed on each individual's computer as well as a videotape of both their hands relative to the keyboard and mouse, and their eyes while viewing their computer display. Second, we developed specific measuring devices to quantify keyboard force and mouse force in the modern office. Third, we completed a study to compare and validate various sampling strategies for determining the intensity of biomechanical factors in the field. In the field, we measured 20 workers for 6 hours on each of four days. We measured both keyboard force and wrist posture while individuals completed both their own work and brief periods of simulated work (~5 minutes). In addition, each subject completed the simulated work in a laboratory setting under two conditions: in a set-up that emulated their own workstation, and at appropriately adjusted workstation. All phases were successfully completed.

Highlights/Significant Findings: In the validation study of the CIM program, we concluded that activity duration cutoffs ranging from 28 to 60 seconds provided unbiased estimates of computer use duration, validating most software programs that typically use a 30 second cutoff. All future studies will use 30 seconds as the activity duration cutoff time.

In the sampling strategy field study of 20 workers, we determined that continuous measures of typing force and wrist postures collected over a two hour period are sufficient to identify differences in exposure intensity metrics between subjects. Furthermore, while simulated work significantly affects exposure metrics, differences across subjects are large enough to determine relative exposure between individuals.

In addition, in a small population of workers, having their work stations configured differently than best practice recommendations did not lead to differences in wrist postures and typing forces.

Translation of Findings: Use of the CIM developed, tested, and validated within this project has demonstrated an association between the variation of *daily* duration of computer use with the *daily* variation of musculoskeletal complaints among a group of intensive computer users. In addition the CIM has been used to validate self-report of daily usage. These findings indicated that daily self-reported computer use duration had a weak to moderate correlation with software-recorded duration, and the relationship between self-report and software recorded duration changed slightly with musculoskeletal symptoms. Self-reports resulted in both non-differential and differential information bias. These findings are also being put to use in a larger scale epidemiological study of office work determining difference in biomechanical exposures across different psychosocial environments.

Outcomes/Relevance/Impact: The primary outcomes of this study are exposure assessment methods that have already impacted the field of computer work-related musculoskeletal disorders through direct measures of suspected risk factors. Direct measures of these physical risk factors in the workplace will improve our understanding of the etiology of musculoskeletal disorders.

Scientific Report:

AIM 1 Final Progress – testing and validating a computer interaction monitor

The first aim as stated in the grant is to *Complete a pilot field study to validate that a software-based computer usage monitor, which records input device activity only, accurately measures duration and frequency of exposures to computer and non-computer work (despite no direct recording of non-input device activities). Current commercially available computer usage monitors record input device activity only. They do not directly record non-input device activities, such as viewing the video monitor. Most interactions are bounded by input device use allowing for indirect measurements of non-input device activities. Our system, hence, arbitrarily assumes that idle times longer than ten seconds are periods of inactivity. With an observational field study of 20 computer workers, we will identify and validate the correct time threshold by comparing a worker's activities videotaped at a computer workstation with those measured by the computer monitoring software.*

WE successfully complete Aim 1 described below. In addition the methods from Aim 1 were translated to other studies comparing daily computer use and changes in keystroke duration associated with fatigue and exposure to repetitive work.

Validating the Computer Interaction Monitor (CIM) Software Program (Primary Aim).

Background:
Integrative computer interaction monitors (CIMs) have become widely used in epidemiologic studies to investigate the exposure response relationship of computer-related musculoskeletal disorders. These software programs typically estimate the exposure duration of computer use by summing precisely recorded durations of input device activities and durations of inactivity periods shorter than a predetermined activity duration cutoff value, usually 30 or 60 sec. The goal of this study was to systematically compare the validity of a wide range of cutoff values.

Methods:
Computer use activity of 20 office workers was observed for 4 consecutive hours using both a video camera and a usage monitor. Video recordings from the camera were analyzed using specific observational criteria to determine computer use duration. This observed duration then served as the reference and was compared with 238 estimates of computer use duration calculated from the usage monitor data using activity duration cutoffs ranging from 3 to 240 sec in 1-sec increments.

Results:
Estimates calculated with cutoffs ranging from 28 to 60 sec were highly correlated with the observed duration (Spearman's correlation 0.87 to 0.92) and had nearly ideal linear relationships with the observed duration (slopes and r-squares close to one, and intercepts close to zero). For the same range of cutoff values, when the observed and estimated durations

were compared for dichotomous exposure classification across participants, minimal exposure misclassification was observed.

Discussion:
In conclusion, a wide range of activity duration cutoffs, between 28 and 60 sec, provided unbiased estimates of computer use duration in good agreement and high correlation with the duration observed from video recordings. Further, exposure misclassification associated with the estimates was minimal. Usage monitors are suggested to estimate computer use durations with good validity, thus they are unlikely to bias epidemiologic findings.

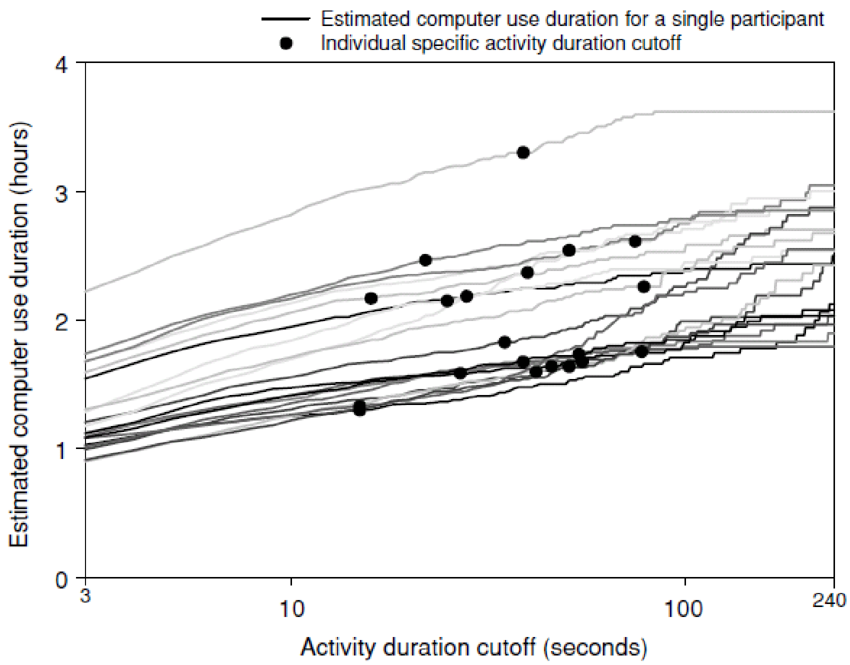


Figure 1: The observed and estimated computer use durations for each participant. Each line represents a single participant and shows how the estimates changed with the activity duration cutoff. The black dot on each line represented the observed duration (the orthogonal projection onto the Y axis) for each participant and the associated individual specific cutoff (the orthogonal projection onto the X axis) that estimated the observed duration with the smallest difference. The relationship between estimated computer use duration and activity duration cutoff emulated a logarithm function, and therefore, the X axis is a base ten logarithm scale to better present the data, especially at shorter activity durations cutoffs.

A Secondary Aim: Using the CIM to measure muscle fatigue due to computer usage.

Background: Exposure to repetitive work can lead to low levels of muscle fatigue, which can affect motor control for rapid movements. Our goal was to determine if the duration of a keystroke during touch-typing can be an indicator for exposure to muscle fatigue.

Methods: A repeated-measures laboratory experiment tested whether keystroke duration during touch-typing changes after a Finger performs sub-maximal isometric Flexion exercises.

Fourteen right-handed touch-typists used right ring finger to perform three 15-min exercise conditions, two isometric exercises and a no-force condition, each on a separate day. Before and after each exercise condition, typing keystroke duration and isometric force elicited by electrical stimulation were measured for right ring finger.

Results: Keystroke duration of right ring finger decreased by 5% (6 ms, $P < 0.05$) immediately after the exercises but not after the no-force condition. Peak isometric finger force elicited by electrical stimulation decreased by 17–26% ($P < 0.05$) for the flexor digitorum superficialis and decreased by 4–8% for the extensor digitorum communis after the isometric exercises.

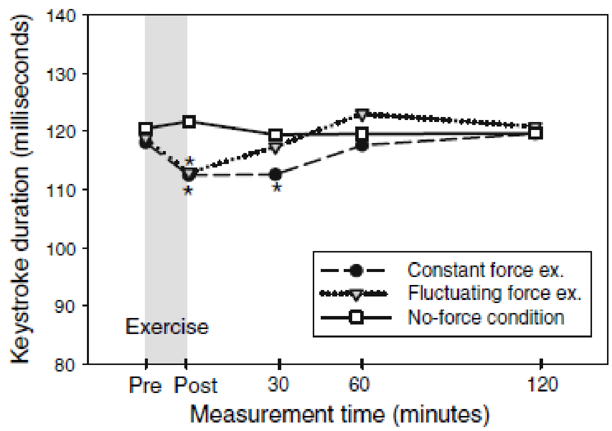


Figure 2: The original values of the keystroke duration measured during each typing test. Asterisk denotes statistical significant divergence (P < 0.05) when compared with the pre-exercise measurement within the same condition. Standard error bars were omitted for clarity

Discussion and Conclusions:
We observed that keystroke duration decreased immediately after submaximal isometric finger exercises of the order of 5%. Similar temporal changes in muscle fatigue and the physiological performance of the FDS and EDC muscles were also observed after the exercises, with the response of the FDS being much larger (of the order of 17–26%). Keystroke duration provided information about the status of finger exercises associated with muscle fatigue and therefore has the potential to serve as an objective measure of the physiological changes in forearm-finger muscles. This pilot study provides a basis to future studies examining how keystrokes can be used to study the exposure–response relationships of MSDs in laboratory and field settings.

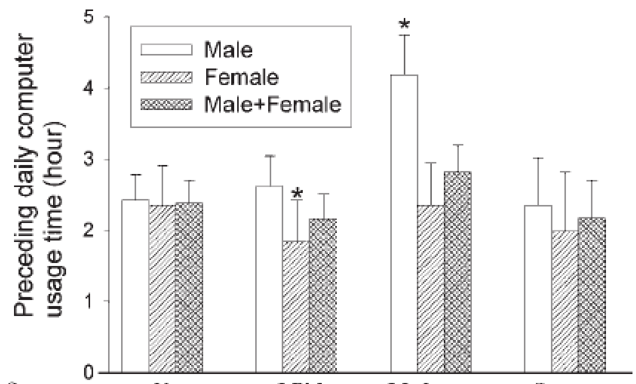
Using the CIM to quantify associations of daily computer usage with daily musculoskeletal complains

Background:
Long durations of computer usage is the most commonly reported risk factor for computer-work related MSDs; however, daily variations in these and their associations with variations in musculoskeletal complaints are not well documented. A prospective study was performed to examine the relationships between daily computer usage time and musculoskeletal symptoms on undergraduate students.

Methods:
For three separate 1-week study periods distributed over a semester, 27 students reported body part-specific musculoskeletal symptoms three to five times daily. Daily computer usage time for

the 24-hr period preceding each symptom report was calculated from computer input device activities measured directly by software loaded on each participant's primary computer. General Estimating Equation models tested the relationships between daily computer usage and symptom reporting.

Results:
Daily computer usage longer than 3 hr was significantly associated with an odds ratio 1.50 (1.01–2.25) of reporting symptoms. Odds of reporting symptoms also increased with quartiles of daily exposure.



Symptom	No	Mild	Moderate	Severe
No. of reports (male/female)	766/673	97/177	28/168	15/16
No. of students (male/female)	14/13	13/11	5/11	9/7

Musculoskeletal symptom severity

Figure 3: Least square means for daily computer usage time preceding each different symptom severity level. Error bars are the standard errors for least squaremeans. * denotes P <0.05 when compared with ''No symptom''.

Conclusions:
We demonstrated that longer daily computer usage time was related to higher odds of reporting daily musculoskeletal symptoms; and we characterized a wide variety of computer input device usage patterns in this cohort of undergraduate students. The observed high musculoskeletal symptom prevalence and the potential relationship between computer usage and symptoms suggested that further research is needed to protect the student population. A potential daily dose–response relationship was also observed among the males in the cohort. The small sample size and the short study period limited us to further investigate the observed gender differences and other potential MSD risk factors. Longer study period, larger study cohort, and collecting data on functional limitations, postures, and transient risk factors are therefore suggested for future studies.

Aim 2 Final Progress: Examining Sampling Strategies for physical risk factors

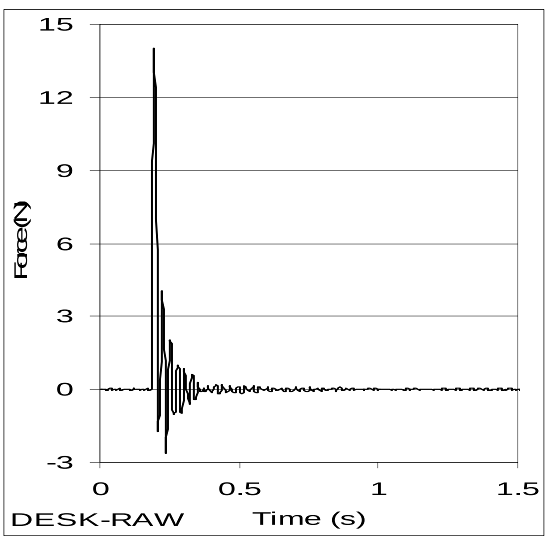
The second aim as stated in the grant is to: *Complete a field study to identify and determine optimal sampling strategies for subject specific exposure intensities of force and postural dynamics. Through a repeated measures design we will compare exposure intensities measured continuously while subjects complete a suite of standardized tasks at a simulated workstation (condition 1) and at their own workstation (condition 2) and while they complete their day-to-day work at their own workstations across three days (condition 3). Using a repeated measures design to compare exposures in these three conditions we will identify and determine the most appropriate and efficient exposure intensity measurement sampling strategy of computer workers.*

Pre - Aim 2 Hardware Development: Removing the vibration artifact from the typing force signal.

A challenge to field measurements for force is the vibration artifact of keyboard inertia on top of the typing force load cell due to compliant keyboard tray supports typical in many office environments. Therefore, before we conducted Aim 2

Back ground:
Reaction force measurements collected during typing on keyboard trays contain inertia artifacts due to dynamic movements of the supporting work surface.

Methods:
To evaluate the effect of these artifacts we measured vertical forces and accelerations while nine volunteers touch typed on a rigid desk and a compliant keyboard tray. Two signal processing methods were evaluated, 1) low pass filtering with 20 Hz cutoff and 2) inertial force cancellation by subtracting the accelerometer signal.



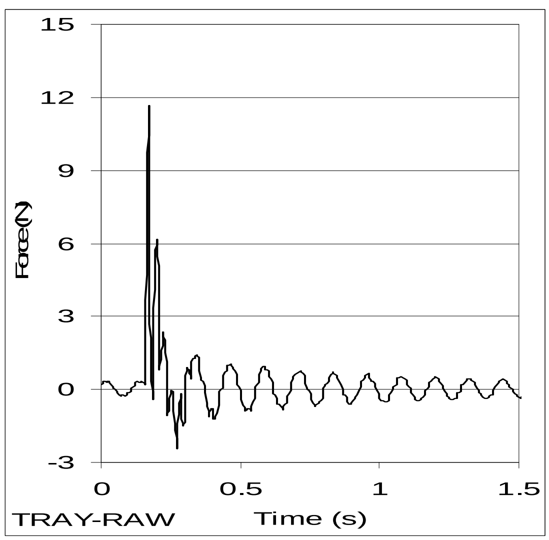


Figure 4: RAW force signal after a single tap on the DESK (left) and TRAY (right) support surfaces. High frequency artifacts are evident for both surfaces, while low frequency artifacts are seen only for the TRAY surface.

Results:
High frequency artifacts in the force signal, present on both surfaces, were eliminated by low pass filtering. Low frequency artifacts, present only when subjects typed on the keyboard tray, were attenuated by subtracting the accelerometer signal. Attenuation of these artifacts altered the descriptive statistics of the force signal by as much as 7%.

Discussion/Conclusions:
For field measurements of typing force, reduction of low frequency artifacts should be considered for making more accurate comparisons across groups using work surfaces with different compliances. High frequency artifacts observed in keyboard force measurements during typing can be effectively removed by low pass filtering. Measuring forces on keyboard trays provide a challenge due to their compliant nature; however, with the use of an accelerometer much of the artifact due to accelerating the keyboard mass up and down can be effectively removed by measuring this acceleration and subtracting the associated inertia load from the force measurements. These factors can have implications for any epidemiological study when comparing forces across a cohort of computer users.

Aim 2: Evaluating various Sampling Strategies to assess the intensity measures of biomechanical factors (Primary Aim).

Background:
Due to large between-subject variability in terms of biomechanical exposure intensities, effective implementation of task-based assessments in epidemiological studies is difficult. However, the variability of upper extremity biomechanical risk factors are largely unknown in computer workers and their specific musculo We completed a repeated-measures study to evaluate different sampling strategies for assessing subject-specific exposure intensities during computer work. We aimed to determine the variability across day, time of day, work and station in exposure metrics of keyboard reaction forces and wrist postural dynamics. A second aim of the study was to determine whether exposure measures collected during simulated working conditions could be used to predict exposure metrics collected during actual working conditions.

Methods:
Continuous measures of wrist extension, wrist ulnar deviation and typing force were collected at work station of 22 office workers while they completed their own personal work over three days (DAY) for six hours per day. Participants were instructed to work as they would normally. Data collected over the six hours each day was grouped into two hour intervals, representing three time of day (TOD) episodes: morning, midday and afternoon. Three times a day (morning, midday and afternoon), participants were asked to complete a simulated work task at their own workstation. The simulated work involved a combination of typing text, pointing and clicking on icons, selecting-dragging-and-dropping of icons, and comprehensive reading exercise. Completing the task took approximately 10 minutes. After the third day of data collection in the field, participants completed the same simulated work at a simulated workstation adjusted to match their own workstation.

Results:
A minimum of 311 observations of typing force and wrist posture were collected across the 22 participants. Every participant provided measurements across time of day and type of work. Overall, the variability in a majority of typing force and wrist postural dynamics exposure metrics between subjects was significantly greater than variability across day, time of day, work and station. Furthermore, the type of work (actual versus simulated) participants performed affected

significantly several exposure metrics while fewer metrics were affected by the station (actual versus simulated) at which participants completed simulated tasks.

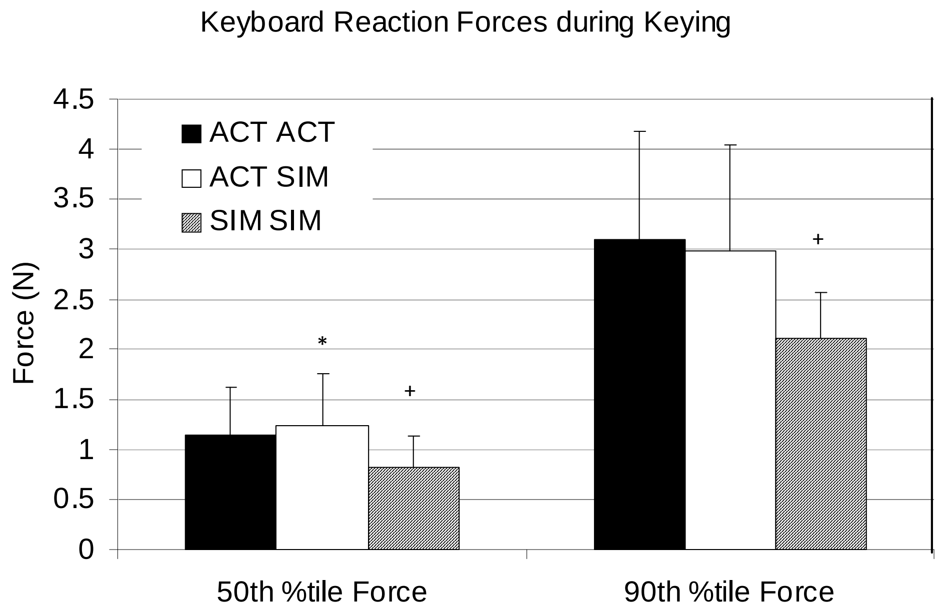


Figure 5: Mean 50th and 90th percentile typing force across all subjects completing actual work at their actual workstation (ACT ACT), simulated work at their actual workstation (SIM ACT) and simulated work at a simulated workstation (SIM SIM). Vertical lines indicate +/- 1 SD. * indicates a significant difference ($p<0.05$) compared to ACT ACT. + indicates a significant difference ($p<0.05$) compared to ACT SIM.

Discussion and Conclusions: Ultimately, the aim of this study was to identify an efficient sampling strategy that could be used to predict subject variability in exposures. By incorporating and modeling inter-subject variability better estimates of an individual's true exposure may be obtained from task based exposure models. Our results indicate continuous measures of typing force and wrist postures collected over a two hour period are sufficient to identify differences in exposure intensity metrics between subjects. Furthermore, while simulated work significantly affects exposure metrics, differences across subjects are large enough to determine relative exposure between individuals. Finally, most exposure metrics for the wrist are unaffected by station, however typing forces are. Since variability in force measures across subjects is not significantly greater than variability within subjects due to station, typing force measures collected at a simulated workstation cannot be used to determine a workers absolute or relative typing force at their own workstation.

Aim 3: Effects of workstation set up on postural and force measurements

Background

Most practitioners and researchers recommend using a computer workstation where keyboard height is set at or below elbow level as recommended by ANSI-HFES-100 guidelines. However, we have observed a large number of participants set their input device support surface above elbow level with a positive tilt. Therefore, we conducted a pilot study to evaluate the effect of workstation configuration on typing force, wrist postures and wrist dynamics.

Methods:
Eight men and twelve women completed a standardized task at a simulated workstation under two configurations, USER and ANSI. For the USER configuration chair height, seat pan depth, keyboard height (defined as the height from the floor to the “J” key), keyboard distance (defined as the distance of the “J” key to the edge of the support surface), keyboard tilt, monitor height and monitor distance were adjusted to emulate the participants’ actual workstation dimensions (measured as part of a separate study). For the ANSI configuration the same parameters were set up according to standardized ANSI-HFES-100 recommended guidelines (Table 2).

Results:
On average, users set their working keyboard 7.2 cm higher than the recommended height. All but 2 subjects tilted their keyboard with a positive slope (Top row higher than bottom row) with a an average slope of 12.5^{o} (5.2^{o} std.dev.)..

No significant correlations (p>0.05) between keyboard tilt and wrist postures, wrist dynamics or typing force were found. No significant differences were seen in mean typing force, wrist postures or wrist dynamics between configurations (Table 3). Wrist accelerations followed similar trends as wrist velocities and are therefore not presented.

Table 1: Comparison of actual workstation set up with the ANSI/HFES 100 set up guidelines

		Left			Right		
Wrist	Metric	USER	ANSI	p-value*	USER	ANSI	p-value*
Extension	10th %tile	20 (19)	22 (12)	0.47	24 (10)	7 (0)	0.90
	50th %tile	35 (9)	35 (9)	0.86	37 (7)	36 (6)	0.50
	90th %tile	43 (8)	42 (9)	0.71	45 (6)	45 (6)	0.74
	95th - 5th %tile	27 (17)	24 (11)	0.11	26 (6)	26 (6)	0.34
	Velocity RMS	25 (8)	23 (7)	0.06	36 (12)	36 (10)	0.85
Deviation	10th %tile	-3 (11)	-2 (12)	0.12	4 (10)	5 (10)	**0.05**
	50th %tile	7 (11)	6 (11)	0.22	13 (10)	12 (10)	0.27
	90th %tile	17 (10)	15 (8)	0.80	20 (10)	18 (10)	0.91
	95th - 5th %tile	24 (10)	20 (9)	0.06	20 (4)	18 (3)	0.09
	Velocity RMS	16 (4)	16 (4)	0.43	19 (7)	20 (6)	0.34
		For both hands					
Typing	50th %tile	0.8 (0.3)	0.9 (0.4)	0.49			
	90th %tile	2.1 (0.4)	2.2 (0.5)	0.64			

*p-value from ANOVA. Significance set at p<0.05

Discussion and Conclusions:
In conclusion, this pilot study identify an alternative workstation configuration which leads to similar wrist postures, wrist dynamics and typing forces observed in users working at the

standardized ANSI configured workstation. The alternative workstation allows greater space under the keyboard support surface for leg clearance as well as improved visual access to the keyboard. Further studies should be conducted to evaluated the effects of this alternative configuration on muscle loads and additional upper extremity postures, particularly the shoulder.

Publications.

Peer reviewed publications describing specific work completed in this study

Asundi K, Johnson P, Dennerlein JT. Effect of sampling strategies on variability in exposure metrics of typing force and wrist postural dynamics during computer work. Ergonomics, In Preparation

Asundi K, Johnson P, Dennerlein JT. Inertial artifacts and their effect on the parameterization of keyboard reaction forces. Ergonomics, 2009 Oct;52(10):1259-64

Asundi K, Johnson P, Dennerlein JT. Postural and force differences between actual user and recommended workstations configurations. Human Factors, In Preparation

Chang CH, Johnson PW, Dennerlein JT. A Wide Range of Activity Duration Cutoffs Provided Unbiased Estimates of Exposure to Computer Use. Journal of Occupational & Environmental Hygiene, 2008; 5(12): 790-6.

Dennerlein JT, DiMarino MH. Forearm electromyographic changes with the use of a haptic force-feedback computer mouse. Hum Factors 2006; 48:130-41.

Dennerlein JT, Johnson PW. Changes in upper extremity biomechanics across different mouse positions in a computer workstation. Ergonomics, 2006. 49, 1456-69.

Dennerlein JT, Johnson PW. Different computer tasks affect the exposure of the upper extremity to biomechanical risk factors. Ergonomics 2006; 49:45-61.

Won EJ, Johnson PW, Punnett L, Dennerlein JT. Upper extremity biomechanics in computer tasks differ by gender. Journal of Electromyography and Kinesiology 2009;19, 428-436.

Peer reviewed publications from studies supported by work completed in this study.

Chang CH, Amick BC III., Chaumont Menéndez C, Katz JN, Johnson PW, Robertson MM, Dennerlein JT. Daily computer usage correlated with undergraduate students' musculoskeletal symptoms. American Journal of Industrial Medicine. 2007: 50(6):481-488

Chang CH, Amick BC, 3rd, Menendez CC, Katz JN, Johnson PW, Robertson M, Dennerlein JT. Daily computer usage correlated with undergraduate students' musculoskeletal symptoms. Am J Ind Med 2007; 50:481-8.

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

Chaumont-Menéndez C, Amick, BC., Chang, CH, Dennerlein JT, Harrist, RB, Jenkins M, Robertson, M, Katz, JN. The epidemiology of upper extremity musculoskeletal symptoms: A pilot investigation on a college campus. Work: A Journal of Prevention, Assessment and Rehabilitation, 2008; 18: 166-74.

Chaumont-Menéndez CC, Amick BC, 3rd, Jenkins M, Janowitz I, Rempel DM, Robertson M, Dennerlein JT, Chang CH, Katz JN. A multi-method study evaluating computing-related risk factors among college students. Work 2007; 28:287-297.

Jacobs, K, Johnson P, Dennerlein J, Peterson D, Kaufman J, Gold J, Williams S, Richmond N, Karban S, Firn E, Ansong E, Hudak S, Tung K, Hall V, Pencina K, Pencina M. University students' notebook computer use, Applied Ergo, 2009 40(3):404-409.

Kotani K, Barrero L, Lee D, Dennerlein, JT. Effect of horizontal position of the computer keyboard on upper extremity posture and muscular load during computer work. Ergonomics. In Press.

Kotani K, Barrero LH, Lee DL, Dennerlein JT. Effect of horizontal position of the computer keyboard on upper extremity posture and muscular load during computer work. Ergonomics 2007; 50:1419-32.

Menendez CC, Amick BC 3rd, Chang CH, Dennerlein JT, Harrist R., Jenkins M, Robertson M, Katz JN. Computer Use Patterns Associated with Upper Extremity Musculoskeletal Symptoms. J Occup Rehabil, 2008 18(2), 166-174

Straker L, Maslem R, Burgess-Limerick R, Johnson P and Dennerlein J. (in press) Evidence-based guidelines for the wise use of computers by children: Physical development guidelines. Ergonomics

Selected conference papers, abstracts and publications

Asundi KA, Johnson PW, Dennerlein JT. Data Selection by Computer Input Device Episodes. X2009 Sixth International Conference on Innovations in Exposure Assessment, Boston, MA 2009

Asundi KA, Johnson PW, Dennerlein JT. Inertial artifacts and their effect on the parameterization of keyboard reaction forces. X2009 Sixth International Conference on Innovations in Exposure Assessment, Boston, MA 2009.

Bruno J. Dennerlein JT. Predicting Biomechanical Patterns in Office Workers Based on Computer Usage Patterns and Individual Anthropometry. X2009 Sixth International Conference on Innovations in Exposure Assessment, Boston, MA 2009.

Chang CC, Johnson PW, Dennerlein JT, Finding the inactivity threshold to accurately estimate computer use time with software. Proceedings of the 6th International PREMUS Conference, Boston, MA, 2007

Chang CH, Dennerlein JT. Gender differences in the relationship between daily computer usage and musculoskeletal symptoms among undergraduate students, Proc. Of the 50th Annual Meeting of the Human Factors and Ergonomics Society, San Francisco, CA, 2006; 1356-1360.

Chang CH, Johnson P, Dennerlein JT. Relating Worker Fatigue with Keyboard Forces and Typing Performance, HCI International 2005, Las Vegas, NV, 2005

Chang CH, Johnson P, Dennerlein JT. Measuring typing forces and keystrike performance. X2004-Exposure Assessment in a Changing Environment, Utrecht, The Netherlands. 2004.

Chang CH, Johnson PW, Dennerlein JT. Finding the inactivity threshold to accurately estimate computer use time with software. Proceedings of the 6th International PREMUS Conference, Boston, MA, 2007

Chang CH, Johnson PW, Dennerlein JT. Keystroke duration during typing changes as the forearm muscles fatigue. *Proceedings of the 16th Triennial Congress of the International Ergonomics Association (IEA 2006),* Maastrict, The Netherlands, 2006

Chang CH, Menéndez CC, Amick BC III, Katz, JN, Robertson M, Johnson PW, Dennerlein JT. Increased computer usage is associated with the reporting of MSD symptoms in 30 University Students. . *Proceedings of the 16th Triennial Congress of the International Ergonomics Association (IEA 2006),* Maastrict, The Netherlands, 2006.

Chang CH, Menéndez CC, Amick BC III, Robertson M, Dennerlein JT. Where and how college students use their laptop computers, Proc. of the 52nd Annual Meeting of the Human Factors and Ergonomic Society, New York, NY, 2008, p12.

Chang CH, Johnson P, Dennerlein JT. (2006) Using a Software as an Exposure Assessment Device to Measure and Detect Computer Users' Muscle Fatigue, NORA 2006 Symposium, Washington, D.C., 274-275.

Chang CH, Johnson PW and Dennerlein JT. (2008) Keystroke durations decreased after finger exercises. The 7th International Occupational Hygiene Association International Scientific Conference, Taipei, Taiwan.

Chang CH, Amick III BC, Chaumont Menende C, Robertson M, Johnson P, Dennerlein JT (2009) Self-reported computer use duration biased the exposure-response relationship of musculoskeletal symptoms. Proceedings of the 17th Triennial Congress of the International Ergonomics Association, Beijing, China.

Dennerlein JT, Asundi K, Chang CH, Johnson PW. Direct Measures for Exposure Assessment of MSD Physical Risk Factors for Computer Users. Proceedings of the International Conference on Ambulatory Monitoring of Physical Activity and Movement (www.ICAMPAM.org), Rotterdam, The Netherlands, 2008.

Jacobs K, Hall V, Brownson E, Ansong E, Markowitz J, DiBiccari L, McKinnon M, Steinberg, Alexander Ing S, Wuest E, Johnson P, Dennerlein J. (2009). The Investigation of the notebook computer experience among university 5tudents. Proceedings of the 17th Triennial Congress of the International Ergonomics Association, Beijing, China.

Jacobs K, Johnson P, Dennerlein J, Peterson D, Kaufman J, Gold J, Williams W, Richmond N, Karban S, Firn E, Ansong E, Hudak S, Pencina K, Pencina M. (in press) . Proceedings of the Human Factors and Ergonomics Society's 53rd Annual Meeting, Santa Monica, CA: HFES.

Johnson P, Ibboston J Dennerlein JT. Comparison of two EVA-based methods for characterizing force exposures during computer work. X2004-Exposure Assessment in a Changing Environment, Utrecht, The Netherlands. 2004.

Johnson PW, Dennerlein JT, Computer input devices: Gender and Stature based differences in exposure. Proceedings of the 6th International PREMUS Conference, Boston, MA, 2007

Johnson PW, Ibbotson J, Chang CH, Dennerlein JT. Turning the Computer Mouse and keyboard into Exposure Assessment Devices. NORA 2006 Symposium. Washington DC, 2006.

Komandur S, Johnson PW, Chang CH, Dennerlein JT, How fast does a computer monitoring program need to run to accurately capture keystroke durations? Proceedings of the 6th International PREMUS Conference, Boston, MA, 2007.