FRUSTRATING COMPUTERS USERS INCREASES EXPOSURE TO PHYSICAL FACTORS

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We quantified physical measures of upper extremity stress, force, posture, and muscle activity as fourteen subjects completed a five page web-based survey. After completing one of the pages, the survey would prompt the user indicating they had completed that page incorrectly. Once acknowledged by the user, the system would redisplay the page with all of the user's responses deleted. Responses to completing the page varied across individuals. Based on a subject's response to a questionnaire, they were grouped into a high or low response group, with the high response group expressing more dissatisfaction with the page design. Force applied to the side of the mouse was higher (1.25N) for the 15 seconds after the display of the error message than the 15s before the error (0.88N) for the high response group (p=0.02). No difference was observed for the low response group. Similarly, the average wrist extensor muscle activity for both the ECR and ECU was 1 to 2 percent MVC higher for the 15s after the error message than compared to the 15s prior to the error for the high response group (p=0.01). Average activity was also 1 to 2 % higher for the second time completing the page compared to the first time. These results suggest that software design and usability can increase exposure to physical risk factors during computer work dependent upon a person's assessment of ease of use.

INTRODUCTION

A class of risk factor or stressor of increasing interest to the development of work related musculoskeletal disorders are psychosocial factors. These psychosocial factors have already been demonstrated epidemiologically to have etiologic importance for cardiovascular disease. In the macro environment, the occupational psychosocial stressor most consistently associated with musculoskeletal disorders is decision latitude or autonomy (Bongers et al., 2002).

Job tasks, mental work load, and verbal coaching have been associated with an increase in exposure to physical and biomechanical stress to the musculoskeletal system associated with work-related musculoskeletal disorders (Wahlstrom et al., 2002; Davis et al., 2002; Van Galen et al., 2002). Both Davis et al., (2002) and Van Galen et al., (2002) added mental tasks while individuals completed either a manual materials handling or computer task, respectively. During manual materials handling, extra mental work load and work pace were associated with increased spinal loading as measured through EMG and kinematic data. During simple point-and-click tasks the increasing mental load induced by a memorization technique increased forearm electromyography in all of the muscles. For both these studies however, personality type was associated with different biomechanical responses to these psychosocial stressors.

Wahlstrom et al (2002) examined several physiological parameters including blood pressure, heart rate, EMG, and applied force to the mouse, while participants completed a computer based text editing task with and without stress. The stress was mainly time pressure imposed from verbal stimuli of the experimenter. During these conditions, all of the physiological measures increased during the stress condition.

Most computer tasks, however, involve only the user and the interaction with the software applications and operating systems. The systems usability may also play a role in creating stressful situations that manifest themselves into various exposures to biomechanical stressors, however this has yet to be studied.

Therefore we quantified upper extremity muscle activity and applied forces to the computer mouse as subjects completed a computer based questionnaire that simulated an error and reset the questionnaire requiring the user to complete the form a second time. We tested the hypothesis that no differences exist before and after the malfunction occurs within the software, deleting the user's work.

METHODS

Fourteen human subjects (5 females, 9 males) participated in the study; these participants ranged in age from 22 to 41 (mean = 28.2 years, standard deviation = 5.3 years). The Harvard School of Public Health Human Subjects Committee approved all protocols and consent forms.

The subjects after providing written consent were seated at an adjustable computer workstation with an adjustable armless chair. The chair was adjusted such that with the feet on the ground the subjects' thighs were horizontal. The table was adjusted such that the home row of the keyboard was at elbow height. The keyboard was placed near the edge of the workstation with the alphanumeric part of the keyboard aligned with the center of the body. The monitor was adjusted such that the top of the monitor was at or below eye level. The mouse was positioned on the same level as the keyboard directly to its right.

The participants completed a five-page web-based survey pertaining to their medical history and most recent job characteristics. This task came at the end of a half-day of experimentation. Subjects were informed that there was one more task to complete, but that the protocol was running behind schedule. They were told that this last task was simple and that most people could fill it out quickly. The subjects were also told that the specific task was designed by the computer support team and the epidemiology department and that they had asked us to test the task.

The web-based survey contained 83 questions distributed over five pages. The types of responses included drop-down (88%), free text (11%), and check boxes (1%). All but one of the free text fields were located on page 3. One of the pages, the one with the largest number of questions, 21, was designed to reset, deleting the user's answers to the questions in an attempt to frustrate the user. Upon completion of the page, determined by the user pressing a "submit" button, the user was automatically prompted by the computer telling the user that they had completed an erroneous free-text field incorrectly and that they had to go back and correct it. After acknowledging the error, the page would reset and all of the previous responses were deleted. The user then had to reenter the data again before continuing. This page was randomly assigned to either page 2 or page 4 of the five page task.

After completing the task, the study participants completed a paper-based questionnaire evaluating the performance and usability of this web-based survey. The survey contained seven questions with responses ranging from 1 for good to 7 for bad. The survey score was the average value of the seven responses.

The electromyographic (EMG) signals from seven muscles were recorded during the tasks using surface electrodes (DE-2.1 Single Differential Electrode, Delsys, Boston, MA) placed on top of the muscle bellies in accordance with Perotto (1994). The wrist muscles monitored were the flexor carpi radialis (FCR), the flexor carpi ulnaris (FCU), the extensor carpi ulnaris (ECU), and the extensor carpi radialis (ECR). The three shoulder muscles monitored included the anterior deltoid (AD), the medial deltoid (MD), and the trapezius (Trap) muscles. The EMG signals were recorded onto a personal computer at 1000 samples per second. A root mean square signal was calculated over a 0.2 second moving window and the data were re-sampled at 200 samples per second. To normalize the results, a series of maximum voluntary isometric contractions (MVCs) were collected for each muscle prior to data collection.

The wrist posture was measured using a goniometric biaxial glove wrist system (Greenleaf Medical Systems, Palo Alto, CA) worn in accordance with the manufacturer's instructions and calibrated using methods in Jonsson (2001). Data were recorded at 20 Hz. The shoulder postural data were collected using a three-axis orientation sensor (3DM Microstrain, Burlington, VT) placed on the lateral midpoint of the right humerus for the first 15 subjects. For the second set of 15 subjects, upper arm posture was measured using Minibird 6-DOF sensor (Ascension Technology, Burlington, VT). A second sensor measured the orientation of the forearm. The arm postural data were collected, through a serial port, into a personal computer at approximately 10Hz. For each task an amplitude probability distribution function (APDF) of the normalized EMG RMS signal and the postures were calculated. .

Forces applied to the side and button of the mouse were measured with a custom design force sensing mouse (based on the work of Johnson et al., 2000). The side sensor consists of four commercially available miniature load cells embedded between two stainless steel plates. A fifth sensor is embedded underneath the button between the button cap and the switch mechanism. For both keyboard and mouse, keying or grip episodes were identified as forces being above a threshold and summary statistics were calculated for each identified episode.

The force and EMG data were parsed into several epochs. These included the data associated with the first time completing the resetting page as well as the repeated completion of the same page. The data was also parsed into the 15 seconds before and after the error acknowledgement was received from the user. For each epoch, summary statistics of the force and EMG data were calculated. Repeated measures methods in JMP (SAS Institute Inc. Cary, NC, USA) were tested for significant differences among the summary statistics across the various epochs.

RESULTS

The levels of frustration and the reactions due to the frustration varied across subjects. The responses from the usability questionnaire ranged from "fine" to detailed accounts of the errors and evaluation of the survey. The usability scores ranged from 1.2 (usable) to 6.4 (not usable) (mean = 3.6, sd = 1.3). The group was then stratified into two groups, a high response group who had higher scores (high) indicating more dissatisfaction with the survey design (score > median) and a low response group who had lower scores (low) indicating less dissatisfaction (score < median).

Time to complete the page was, on average, faster the second time through, but not significantly. However, when the groups were stratified, the low response group's time improved significantly (Table 1). The high response group remained on average unchanged.

Table 1: Time to complete the page in seconds (* $p< 0.05$)

	Overall	Low*	High
First Time	91 (12)	94 (9)	88 (14)
Second Time	80 (17)	72 (16)	87 (14)
Difference	11 (22)	22 (22)	1 (18)

For the high response group, forces applied to the side of the mouse increased significantly ($p = 0.02$) after the resetting of the web page (Figure 1). The forces measured during the first time through the page were not that different in the last 15 seconds compared to the whole period. Once

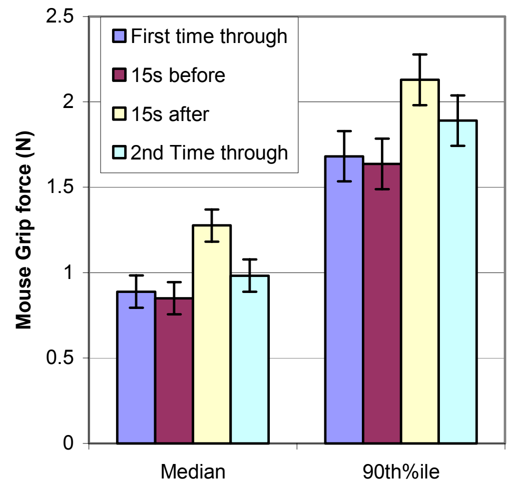

Figure 1: Mouse thumb forces during completion of the survey web page for the high response group. Forces increase significantly during the first 15 seconds, just after the loss of data.

the page reset, mouse grip forces increased significantly for the first 15 seconds. The forces decreased overall the second time through, but remained slightly higher than the first time. No significant trends were observed across these epochs for the low response group. There were no differences in the forces applied to the mouse between the two groups of individuals.

For the high response group, muscle activity (EMG) of wrist extensor muscles increased significantly immediately after the pages reset and was higher the second time through the page (Figure 2 and 3). Both the 10^{th} and 50^{th} percentile summary statistics increased. Differences were not observed for the 90^{th} percentile. No differences were observed for the shoulder muscles or the flexors. Differences were not observed within the low response group.

DISCUSSION

These data indicate that exposure may depend upon the usability of the computer software. Frustrating users in this simple environment increased forces applied to the mouse and increased EMG activity of the wrist extensor muscles. These data also suggest that other factors, such as individual factors, may confound the results. Increases in exposure

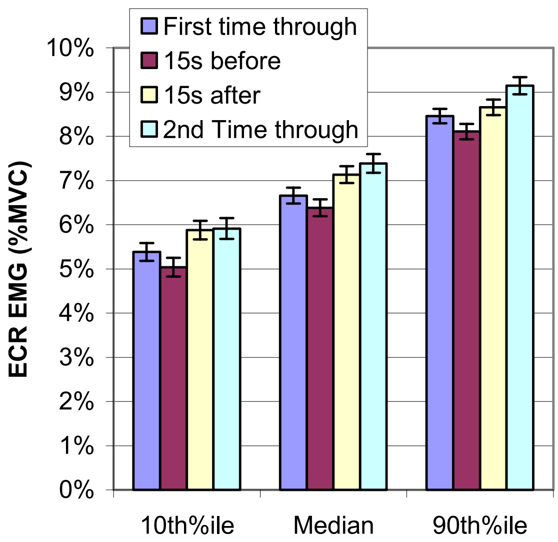

Figure 2: Extensor Carpi Radialis (ECR) EMG activity was higher after the form malfunction

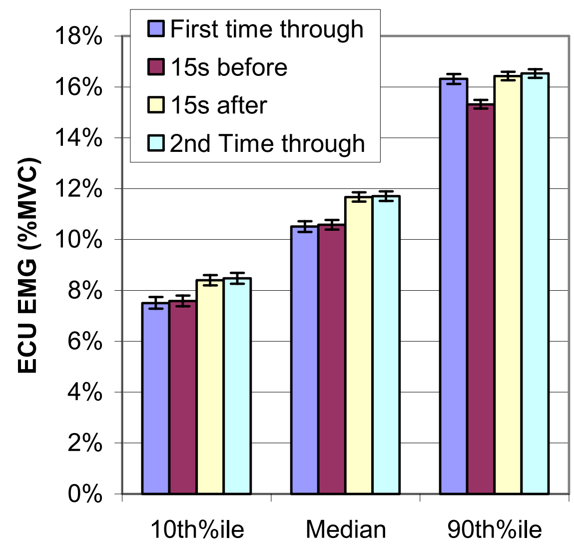

Figure 3: Extensor Carpi Ulnaris (ECU) EMG activity was higher after the form malfunction.

were only observed among those who were critical of the usability of the software.

These conclusions however, are limited to the laboratory studies presented here. First, the tasks completed were simulated and it is difficult to simulate true user frustration. Furthermore, frustration is a subjective emotion that can depend upon many different individual factors. These types of individual differences have been observed elsewhere. Both Marras et al., (2000) and Van Galen et al., (2002) have observed that responses depend on either personality type or a disposition towards being anxious, respectively. So there is a precedent for stratifying our small study population. Unlike the previous studies, we relied on self-reported levels of frustration to divide our groups. So while not an indication of personality types, they are a level of frustration more similar to the mood evaluations of the subjects in Wahlstrom et al (2002) study. Anther aspect about the frustration method in a laboratory based study, is that there is no significant consequence of the errors. This may be why the individual factors play a large role. It is difficult to understand how these factors may manifest in a real office setting.

In conclusion, frustrating the user through simulated software malfunction illustrates how stress manifests to increased exposure to physical risk factors for WRMSDs.

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