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Evaluation of Three Methodologies for Assessing Work Activity During Computer Use

The overall goal of this study was to evaluate three separate methodologies for gathering work activity information among computer users. These methodologies included worker self-report, work sampling, and activity monitoring. A repeated measures design was employed whereby data were collected simultaneously on each subject (n = 51) across three consecutive workdays. Exposure information gathered included keying time, mouse usage, and time spent performing various work tasks (i.e., writing, proofreading, handling documents). Subjects were recruited to represent a wide range of keyboard activity and mouse usage. The study found that worker self-reports overestimated actual keyboard usage by a factor of approximately 1.5 for workers using the keyboard an average of 4 hours per day to a factor of 4 for workers using the keyboard an average of 30 min per day. On average, there was an approximate twofold difference between worker self-reported keying time and that obtained via activity monitoring and work sampling. This trend was similar with regard to time spent using the computer mouse. Worker self-reported mouse usage was approximately twofold higher than that obtained via activity monitoring or work sampling. Self-reported exposure information not only resulted in different estimates, but showed greater variance compared with the other methodologies. The results of this study suggest that the use of worker self-reported exposure information on keying time and mouse usage may not represent an accurate account of time spent performing these tasks. In the context of epidemiological studies work sampling and/or activity monitoring would be more suitable methodologies for obtaining such information.

Keywords: activity monitoring, exposure assessment, self-report, work sampling

Musculoskeletal complaints are common among computer users.[1–3] The etiology of upper extremity musculoskeletal disorders (UEMSDs) is not known with certainty, but it is generally understood that a variety of work-related and personal factors play roles.[4,5] Physical stressors that have been associated with the development of UEMSDs include repetitive and sustained exertions, forceful exertions, awkward postures, localized contact stresses, and vibration.[6,7] It also has been suggested that certain aspects of the work organization (i.e., monotonous work, machine-paced work, close performance monitoring) may contribute to the expression of musculoskeletal symptoms.[1,2,8] With regard to the development of disease, however, the relative contribution of each factor and the interaction among them remains unknown.

A number of epidemiological studies have been conducted among computer user populations.[1,3,9–21] Although a number of these studies point to an association between visual display terminal (VDT) use and musculoskeletal disorders, methodological limitations and inconsistent results prevent specific conclusions from being drawn.[22]

It has been suggested that one of the major factors limiting the expansion of understanding of work related musculoskeletal disorders relates to the difficulty in exposure definition, exposure assessment, and exposure evaluation.[22,23] To further elucidate this relationship, standardized exposure assessment methods that are consistent

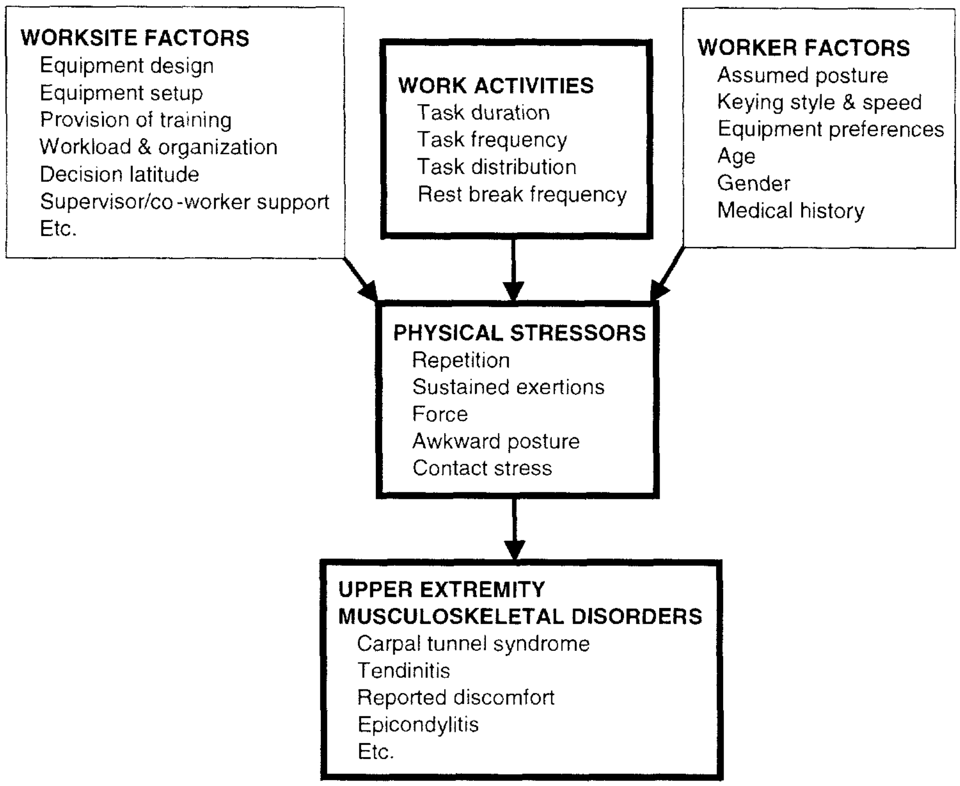

FIGURE 1. Research model of risk factors for UEMSDs among computer users

and valid are necessary for exposure quantification. It is estimated that during the 1990s between 40 and 80 million VDTs were used in the U.S. workplace.[24] Due to the continued proliferation of computers in both the home and workplace, the relationship between VDT use and UEMSDs, and their subsequent prevention, is an area deserving of further research. The National Institute for Occupational Safety and Health has identified the development and evaluation of ergonomic exposure assessment methods as one of the priority areas in the implementation of the National Occupational Research Agenda.[25]

The overall goal of the current study was to develop or enhance and subsequently evaluate exposure assessment methodologies for use within epidemiological studies among computer users. The methods were specifically tailored to assess ergonomic risk factors within office and computer-related work that have been associated in the development of upper extremity musculoskeletal disorders. A research model is presented in Figure 1 to describe and relate the metrics examined in this study to physical ergonomic risk factors and their association with UEMSDs.[1,4,13,22,23] The goal of ergonomic epidemiological studies is to assess the relationship between ergonomic stressors and UEMSDs. Office and computer work often involve a complex set of work activities, work site factors, and factors inherent to the worker that can directly influence the level of physical ergonomic risk factors. Many previous studies have either examined the relationship between work activities and the development of UEMSDs; or the combination of work activities and work site factors and the development of UEMSDs. This is mainly due to the convenience of obtaining these metrics and the fact that many of these factors can be changed in the course of implementing ergonomic interventions.

The focus of the present study is highlighted in Figure 1 and concentrates on examining the nature of the work activities (i.e., hours of keying, hours of mouse usage, task distribution). Several prior epidemiological studies suggest that there is an exposure-response relationship between the hours of VDT use per day and the development of UEMSDs.[10,11,26] This risk may also be influenced by the distribution of tasks and the duration of each task that influence the level of repetition and recovery time. Task requirements such as duration, frequency, and distribution may be utilized to provide a measure of the workload and may ultimately represent the level of repetition or static postures inherent to the job and job tasks.

The three methods for gathering exposure information in this study were worker self-report, work sampling, and activity monitoring. These methods were chosen for development and evaluation due to their wide use within epidemiological studies, ease of administration, and/or the usefulness of the information obtained.

Worker self-reported information has been used widely in past epidemiological studies to gather data on work tasks and work duration.[1,9–11,13,16,17,27,28] The advantages of worker self-report surveys include the low expense and minimal time and personnel commitment necessary for administration. The accuracy of worker self-reported information, however, has not been clearly established. The design should be such that questions are easily understood, do not lead the subject to a specific response, and require clear responses. Other factors that may bias the results obtained from self-report surveys include symptom status and psychosocial influences.[29] One study among computer users found that workers, regardless of symptom status, estimated the average time spent keying twofold higher than that obtained from independent observations.[10] Another study comparing the results of worker self-reports and work sampling found a lower degree of discrepancy between the two methods, but self-reported hours of VDT use was always higher than that obtained from work sampling.[29]

Work sampling is an observer-based method where the goal is to estimate the proportion of time a worker performs a defined set of tasks.[30] Developed in the early thirties, this methodology is particularly useful in the analysis of irregular or nonrepetitive tasks.[31] Traditionally, work sampling was performed by a trained observer making random observations on site.[32] This approach, however, may be biased by the arrival of the observer at the workstation. It has been suggested that such bias may be reduced through the use of video cameras to record the work activities with analysis occurring afterwards.[30] This method has a number of advantages including allowing for the collection of a large number of samples in a minimum of time and extending observations over the entire work shift.[32] Work sampling has been used in several prior epidemiological studies to provide an estimate of the proportion of time spent on computer and office-related tasks.[10,11,33] It also has been used in several studies to assess both computer and mouse usage patterns.[29,34]

Activity monitoring, which involves collecting real-time data via instrumentation, makes it feasible to sample over long time periods. It is often used in the context of ensuring worker attainment of performance standards (i.e., number of keystrokes, accuracy rate, number of phone calls). Its use as a method for determining exposure information within the context of epidemiological studies has been limited. One epidemiological study utilized the number of keystrokes per day as an exposure variable to represent repetition for one of the job titles (n = 174) among a worker population.[2] No significant association was found between keystrokes per day and reported upper extremity symptoms or physician-confirmed diagnosis of UEMSDs. In this study keystroke information was available only for those workers with a relatively low number of keystrokes compared with the other workers in the study.

In the present study, three methods (activity monitoring, work sampling, and worker self-report) were used to gather exposure information on work populations representing a wide variety of office and computer-related tasks. The specific objectives of the present study were to refine and enhance three methods for assessing work activity among computer users and to compare the estimates of keyboard and mouse usage activity among the three methodologies.

METHODS AND MATERIALS

Subjects

Study sites were selected to obtain a wide variety of job titles and levels of keyboard activity and mouse usage. Special efforts were made to recruit workers across four work activity categories. These activity categories were low, medium, and high keyboard activity, and mouse users as defined in Table I. Subjects were recruited from three facilities: various administrative units of a military facility; a word processing operation of an insurance company; and a medical transcription service. Subjects were excluded from the study if they used another computer in addition to the one at their workstation for more than 5% of the workday.

Prior to participation, all subjects were made aware of the study protocol, and each provided written informed consent, which had been approved by the university's Institutional Review Board. All data were collected during the regular work shift. Personally identifiable results of the data collected were not provided to employers. Subjects at the medical transcription service were provided minimal compensation for their participation because their work payment was based on incentives. Subjects at other sites were not compensated for their participation.

A total of 51 subjects participated in the study. Of these subjects, 35 were from a Midwestern military base; 11 from a medical transcription service; and 5 from a word processing center of an insurance company. A total of 35 (68.6%) were female and 16 (31.4%) were male. The average age of the subjects was 38.6 (SD = 9.1) years. In terms of keying activity, the low, medium, and high keying groups included 14, 13, and 12 subjects, respectively. A total of 12 subjects were included in the "mouse using" group.

Procedures and Equipment

The study was performed using a repeated measures design. Data were collected on each participant simultaneously using all three methodologies across 3 consecutive working days. A detailed description of each method and the overall data collection procedure is further described in following paragraphs.

Electronic Activity Monitoring

Six activity monitors were fabricated and used to monitor and record computer use information including number of keystrokes; keying time; number of mouse clicks; distance of mouse travel; total mouse usage time; and time hands were held statically over the computer keyboard. The monitors consisted of external microprocessors that monitored and recorded the signal between the keyboard or mouse and computer. Monitoring equipment was connected to the workers' computers directly, allowing them to use their own keyboards and computer mice. The recording of keyboard and mouse activity began once the computer was turned on, because the monitors drew power directly from the computer. Total keying time was monitored and recorded when successive keystrokes occurred within a 5-sec interval. An infrared light curtain was developed to record the time in which the subject's hands were located on the keyboard. The light curtain could not be used at every subject's workstation due to interference from workstation and keyboard design.

Mouse usage was also monitored and occurred when mouse travel or mouse clicks were registered within a 5-sec period. The monitors were programmed to record each 15-min interval across the workday. The data were then downloaded to a laptop computer (Macintosh Powerbook 170) using Labview® 3.1.1 software.[35]

Work Sampling

Subjects were videotaped using commercially available video recorders (JVC GRAX-710) with a built-in time lapse feature. The cameras were attached to tripods at an oblique angle to the worker and in a location that minimized interference. All subjects were filmed at a sampling rate of 1 sec every 60 sec throughout the entire workday (i.e., 480 samples for an 8-hour workday). A date and time stamp were also recorded to facilitate analyses. The videos were analyzed by playing the videotapes at one-fifth the normal speed and entering a number into a computerized spreadsheet for each observation. Each number corresponded to 1 of 10 specific tasks/activities, as outlined in Figure 2. If the worker was performing multiple tasks during an observation, each task was entered into the task sheet. The percentage of time spent on a specific task was then determined by dividing the number of observations recorded per task by the total observations.

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TABLE I. Previously Defined Exposure Categories for Subject Selection

Category	Categorization Criteria	Production Standard
Secondary computer users (low keying activity)	rely on computer to compose text, analyze data sets, or perform engineering analysis	based on completion of job tasks may vary from minutes to months
Data processors (medium keying activity)	requires brief or intermittent keyboard use to retrieve or enter information may provide or obtain information from a second party via the telephone worker may sort through hard-copy records or files	number of phone calls number of successful phone calls number of files processed
Data entry operators (high keying activity)	transfer data to computer from paper copy or dictation high number of keystrokes	keystrokes per hour number of documents processed
Mouse users	rely on computer mouse for the majority of data manipulation	based on completion of job tasks may vary from minutes to months

Worker Self-Report

Subjects completed a brief questionnaire at the end of each workday requesting that they estimate the amount of time (to the nearest half hour) spent on various work tasks including typing at the computer keyboard, using the computer mouse, handling documents, using the phone, writing with a pencil or pen, and other tasks. The questionnaire was pilot tested among a group of six travel agents and three secretaries to evaluate the clarity of task definitions, the preferred metric for estimating work task allocation (percentage or number of hours), and ease of use. Comments were incorporated into the final questionnaire.

The definitions for each of the tasks included in the questionnaire corresponded to the tasks defined within the context of the work sampling procedure. The questions were adapted from a questionnaire used by the National Institute for Occupational Safety and Health[11] to evaluate work tasks and activity among a group of reporters and other newspaper workers. Based on the pilot testing, the wording of the questions for the present study, however, was changed so that the worker estimated the number of hours (to the nearest half hour) rather than the percentage of time spent performing each task. For example, in the final questionnaire, the question specific to the amount of time spent keying was stated as, "How much time did you spend typing at the computer keyboard?" This question also included an additional instruction for the worker to include only the time spent typing at the keyboard and not to include time spent sitting at the computer workstation performing other tasks. Workers were also asked to estimate the total amount of time spent at their workstations and total amount of time away from this location.

RESULTS

Data Analysis

Statistical tests were performed using STATA, version 5.0.[36] Nonparametric tests were performed because the data did not follow a normal distribution as determined by the Shapiro-Wilk test. The Wilcoxon rank sum test was used to test the means for two independent groups of data. The Kruskal-Wallis test was performed on data with more than two groups. Rank order associations were determined through calculation of Spearman rank correlation coefficients (Spearman's rho). Statistical tests were considered significant if p-values were less than or equal to 0.05.

The data gathered from activity monitoring represented approximately 1200 hours of real time monitoring with an average of 7.84 ($\pm$1.26) hours per subject per day. A total of 64,212 samples was gathered by work sampling representing an average of 420 ($\pm$78) samples per worker per day. Exposure information obtained via questionnaire was available for 51 subjects for 3 consecutive days.

Summary of Keying Time Across Activity Groups

Figure 3 displays the average keying time obtained from activity monitoring by activity group. The mean keying time per day for the "low keying" group was 0.5 hours (SD = 0.3). The "medium keying" and "high keying" groups averaged 1.7 (SD = 0.7) and 4.1 hours (SD = 0.9), respectively. The group defined as mouse users averaged 0.3 hours (SD = 0.3) of keying time. The mean keying times for the three keying groups were significantly different ($p < 0.01$). The low keying group and mouse-using group, however, were not significantly different with regard to keying time.

Comparison of Keying Times Across Three Methodologies

Keying time data obtained by the three separate methodologies are displayed in Figure 4. Mean keying times obtained by activity monitoring and work sampling were not significantly different. However, mean keying time from worker self-report (mean = 3.6, SD = 2.5 hours) was significantly higher ($p < 0.01$) than that obtained by activity monitoring (mean = 1.6, SD = 1.6 hours) or work sampling (mean = 1.9, SD = 1.7 hours). This trend was consistent across all four activity groups. There was a positive rank order association between keying time data obtained by activity monitoring and work sampling (Spearman's $\rho = 0.93$, $p < 0.01$). A positive rank order association was also observed between keying time data from activity monitoring and worker self-report (Spearman's $\rho = 0.78$, $p < 0.01$).

There was an inverse proportional relationship between activity group and self-reported keying times. For example, workers in the low keying group reported, on average, keying time that was approximately 4-fold higher (2.1 versus 0.5 hours) than that obtained from activity monitoring. Conversely, workers in the high keying group reported keying time that was 1.6-fold greater (6.6 versus 4.1 hours) compared with activity monitoring.

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Computer spreadsheet
for videotape analysis

Time	Task 1	Task 2
9:00AM	1	-
9:01	1	-
9:02	2	-
9:03	2	-
9:04	1	-
9:05	5	-
.	.	-
.	.	.
.	.	.
.	.	.
.	.	.
4:57	1	-
4:58	2	-
4:59	1	-
5:00PM	1	-

8 hours = total of 480 samples

→

Task	Number	Percentage
1	205/480	42.7%
2	35/480	7.3%
3	15/480	3.1%
4	0/480	0%
5	50/480	10.4%
6	13/480	2.7%
7	32/480	6.7%
8	72/480	15%
9	0/480	0%
10	58/480	12.1%
TOTAL	480/480	100%

TASK CATEGORIES
1 = using computer keyboard
2 = hands over keyboard/not typing
3 = using the phone
4 = reading
5 = handling documents
6 = talking with co-workers
7 = using the mouse
8 = not at workstation
9 = writing
10 = other task not listed above

FIGURE 2. Example of spreadsheet and data reduction procedure for work sampling methodology

Estimates of Static Exertion

Figure 5 displays data obtained from activity monitoring including time spent and total time hands were held over the keyboard without keying. These data were available for 32 of 51 subjects. The pooled data show that during the time the hands were held over the keyboard, 75% of that time was spent keying, whereas 25% of that time the hands were held statically over the keyboard without keying. The high keying group averaged almost 1 hour per day (0.9 hour) when the hands were over the keyboard without keying.

Mouse Usage

Figure 6 displays the average mouse usage per day by activity group across methodologies. The high mouse usage group averaged 2.0 hours per day as measured through activity monitoring. This compares to approximately 0.2 hours averaged by the low mouse usage group (keying groups). For all study participants, mouse usage time from worker self-report (mean = 1.4, SD = 1.9 hours) was significantly higher ($p < 0.01$) compared with that obtained from activity monitoring (mean = 0.6, SD = 1.0 hour). Mean mouse usage times obtained by activity monitoring (mean = 0.6, SD = 1.0 hour) and work sampling were not significantly different (mean = 0.8, SD = 1.1 hours). There was a positive rank order association between mouse usage data obtained by activity monitoring and work sampling (Spearman's $\rho = 0.85$, $p < 0.01$). A lower positive rank order association was observed between keying time data from activity monitoring and worker self-report (Spearman's $\rho = 0.71$, $p < 0.01$).

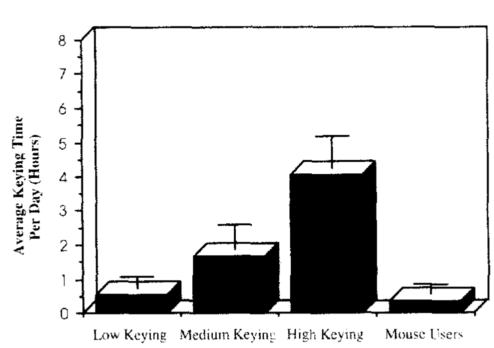

FIGURE 3. Average keying time by activity group

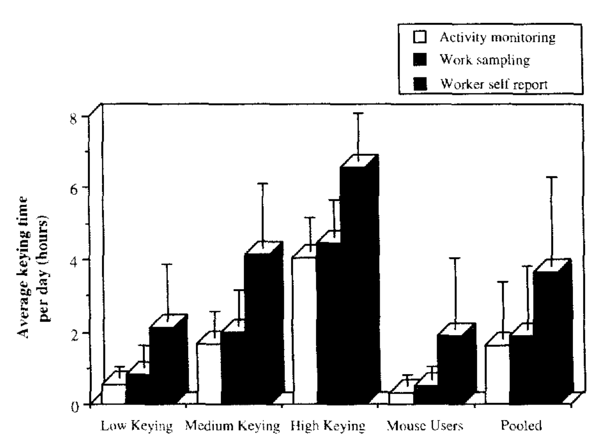

FIGURE 4. Comparison of mean keying times across three methodologies

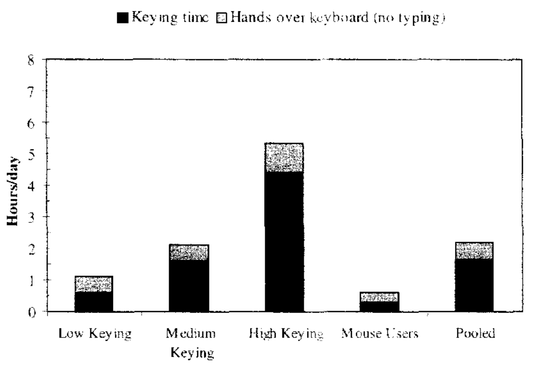

FIGURE 5. Estimates of keying time and time hands were held statically over keyboard without keying

DISCUSSION

An interesting result from this study concerns the approximate twofold (2.2 times higher) difference obtained between worker self-reported keying time (mean = 3.6 hours) and that obtained through activity monitoring (mean = 1.6 hours) and work sampling (mean = 1.9 hours), as shown in Figure 4.

On average, the level of overestimation by worker self-report differed across activity groups. The low keying group overestimated the amount of keying time four times higher than that obtained by activity monitoring. Workers in the high keying group overestimated keying time 1.6-fold higher than that obtained by activity monitoring. This result is not surprising because it is theoretically impossible for the high keying groups to overestimate keying times longer than the number of hours worked. As a result, high keying groups have, proportionally speaking, a smaller time period from which to overestimate.

Similarly, average mouse usage based on worker estimates was approximately two times greater than that obtained from electronic activity monitoring (Figure 6). As with the estimates of keyboard usage, this ratio is likely to change with increasing mouse usage (i.e., CAD or graphic design work).

The results comparing keying time information from activity monitoring and work sampling are encouraging (Figure 4). The average keying time obtained by work sampling (1.9 hours) was somewhat higher than that obtained by activity monitoring (1.6 hours). This difference, however, was not statistically significant. A possible reason for the small difference noted may be explained by discrepancies in the analysis of videotapes. In some work sampling frames it was difficult to discern whether the worker was keying or statically holding the hands above the keyboard. Incorrectly identifying a worker as keying would artificially inflate the proportion of time the worker was identified as keying and may explain the variation between outcomes obtained between activity monitoring and work sampling.

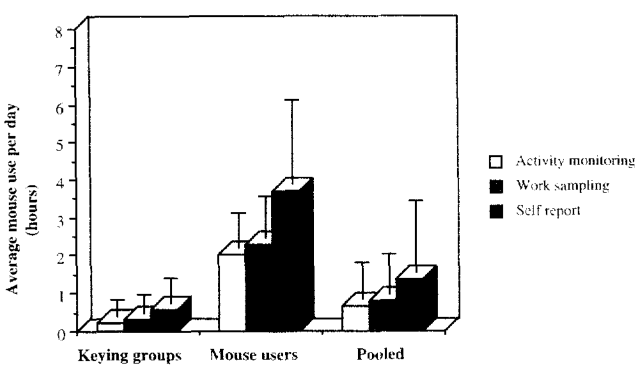

FIGURE 6. Average mouse usage time by usage group and methodology

A previous study compared VDT use information obtained from worker self-reports with that of behavioral sampling.[29] Behavioral sampling consisted of 3 min observations at regular 15-min intervals, with the most prominent behavior entered into a checklist. A total of seven reporters and six copyeditors were observed across 4 work days. The study found that VDT use information from worker self-report (4.5 hours for reporters and 5.9 hours for copyeditors) compared somewhat favorably with that of behavioral sampling (3.2 hours for reporters and 4.1 hours for copyeditors). The correlation between self-reported and observed VDT use was moderate, but not significant ($r = 0.50$, $p = 0.08$). The present study found a positive rank order association between activity monitoring and worker self-report (Spearman's $\rho = 0.78$, $p < 0.01$). However, comparing the arithmetic averages, workers reported twice the amount of keying time compared with activity monitoring or work sampling. Differences found between these two studies may be due to a number of methodological differences including the format of the questions for eliciting VDT use information, sampling methodology, sample size differences, and differences in VDT use across study populations.

Investigators conducting an epidemiological study among newspaper employees found results similar to the present study.[10] In the study, information on VDT use was gathered via worker self-reports and through work sampling. A randomly selected sample was chosen for observation consisting of 40 cases (workers having evidence of a work-related musculoskeletal disorder) and 40 controls. Workers were observed every 15 min over the course of a workday (approximately 30 samples were collected per worker), and the task performed was recorded. This information was compared with that obtained from worker self-reports. The average number of hours spent keying reported by cases was 4.5 compared with 2.5 from work sampling. Controls, on average, reported 3.9 hours of keying versus 1.9 obtained from work sampling. Thus, an approximate twofold discrepancy in keying time was obtained between worker self-reports and work sampling, as observed in the present study.

Activity monitoring is the most accurate method for collecting information on keyboard and mouse usage. It allows for real-time monitoring and large sampling rates to be collected. In the present study this method required the least amount of time for data reduction and analysis. The data were downloaded to a computer for prompt analysis with a spreadsheet program to determine keying and mouse usage patterns. This method also has the flexibility to identify different users using the same computer (i.e., workers enter a user code when using the computer). This might be useful when information on computer use is needed among workers using multiple computers within the same work environment.

One disadvantage of activity monitoring concerns the requirement for specialized equipment that must be compatible with computer equipment in use. Electronic activity monitoring can be implemented using either external hardware or software on the subject's computer. For the purposes of this study, external hardware was chosen for its ease of setup and the likelihood of encountering employers reluctant to allow software to be loaded on their computers. Another disadvantage is that the monitors must

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be connected to the keyboard and mouse of the subject's computer. This may not be practical nor allowable in all field situations as it may not be looked on favorably by management or workers.

The results of this study suggest that work sampling provides a close, but consistently higher, estimate of keyboard and mouse usage as compared with electronic activity monitoring. This method has several advantages. It can be performed with minimal intrusion and allows for a large number of samples to be collected. Additionally, work sampling can provide additional information about exposures during other work tasks within the view of the video camera that may contribute to musculoskeletal symptoms. This method may also be combined with postural assessments to estimate the proportion of time workers spend in various postures.

One disadvantage of the work sampling method is that it requires specialized equipment (video cameras with a programmable time lapse function) and a large time commitment for data reduction. In this study approximately 200 hours were required for analysis of the videotapes. A total of 1200 total work hours were sampled in this study, so the time allotment to analyze one 8-hour day (480 samples) was approximately 80 min. This time and resource commitment could be reduced by opting for a lower sampling rate. Another potential disadvantage of work sampling is that in some instances workers and/or management may not welcome a video camera in the work environment. Additionally, this approach is not appropriate for workers performing a large proportion of tasks away from their desks, as such activities would not be captured by a stationary video camera. In such instances it would be necessary to either have an analyst on site performing work sampling or have workers perform self-analysis work sampling (workers record time periods and tasks performed).

Questionnaires completed by workers provide the least expensive and time-consuming method to gather task and exposure information. Although there was a positive rank order relationship between information obtained from worker self-reports and activity monitoring, workers tended to overestimate the amount of daily keying time. The same trend was observed for mouse usage patterns. As evidenced by this study, it is difficult for workers to accurately estimate the amount of time spent on keying and performing other work tasks. It is possible that the level of overestimation from self-reported information may be reduced. One possibility for increasing the accuracy of information from self-reports is to include a section where workers can record the actual tasks and time period spent on each task throughout the day. This approach obviously requires more time and effort on the part of the worker and may not be practical in certain work environments.

Each method has its own strengths and limitations that should be taken into consideration. Ultimately, the method or methods of choice should be selected based on the study objectives, resources, setting, and time constraints. However, for epidemiological studies in which accurate exposure information is essential for examining the exposure-response relationship, more objective measures of assessing exposure are warranted. From the results of this study, relying on worker self-reported information in the context of an epidemiological study could bias the exposure-response relationship. If the error classification is nondifferential, the exposure variable does not vary according to the value of another variable. Depending on the correlation between the true and imperfect measure of exposure, such nondifferential error would drive the exposure-response relationship to the null hypothesis (i.e., odds ratio = 1.0).[37] If, however, the error classification is differential, the effect on the measure of association could be in any direction (biased either away or toward the null hypothesis).

One limitation of this study that deserves further examination concerns how questionnaire design affects worker self-reported exposure information. Although every attempt was made to ensure the clarity and response accuracy of the questionnaire through pilot testing, the accuracy of worker self-report might be increased through different wording of the questions. For example, comparisons could be made between worker estimates based on a percentage basis (i.e., what percentage of the day do you spend keying?) versus estimates based on the total number of hours (i.e., how many hours did you spend keying?).

To evaluate external validity, the methods should be used to assess the relationship with health outcomes among workers representing a variety of keyboard and mouse usage. The population (n = 51) in this study was not large enough to perform such an in-depth epidemiological investigation.

As previously discussed, adequately assessing the workload during computer use has implications for determining the exposure-response relationship and for developing guidelines and policy regarding computer use. The results of this study suggest that studies based on worker self-reported information probably overestimate the actual amount of keyboard use. As a result, any significant symptoms are probably associated with lower levels of actual keyboard use than suggested by the data. In addition, because the reporting of keyboard usage is disproportionately higher for lower levels compared with high levels of use, the actual difference between populations with low and high keyboard use would be greater than reported. Additionally, the statistical power for testing hypotheses that musculoskeletal symptoms are associated with actual keyboard use may be greater than previously reported.

It is generally reported that workers are at increased risk if they use VDTs for 4 or more hours per day.[1,26] Most of the studies that were reviewed to arrive at this conclusion relied on worker self-reported information, and given the results of the present study, perhaps the risk occurs at a somewhat lower level of daily VDT use, assuming classification error is nondifferential. To develop guidelines based on accurate measures of computer use and the association with UEMSDs, further development and evaluation of exposure metrics is warranted. Hopefully, this will lead to a better understanding of the threshold dose that can be used in policy development to help reduce and prevent UEMSDs among computer users.

CONCLUSIONS

(1) The study found that worker self-reports overestimated actual keyboard usage by a factor of approximately 1.5 for workers using the keyboard an average of 4 hours per day to a factor of 4 for workers using the keyboard an average of 30 min per day.

(2) The study found that self-reported estimates of keyboard and mouse usage for an 8-hour day were, on average, 20 min greater than that obtained from activity monitoring regardless of the total number of minutes used for work sampling.

(3) Advantages of work sampling include that a minimum of equipment is required and it can provide information about exposures related to all tasks within the field of view. Disadvantages of this method include the possibility of video recording being perceived by the employer or worker as intrusive and thus not being allowed. Additionally, this particular method of work sampling will miss work tasks outside the field of view unless additional techniques are used to capture such tasks.

(4) Work sampling requires approximately 10 min of analysis time to analyze 1 hour of data (sixty 1-sec samples). Although this time allotment is reasonable for short-term use, it could become onerous for large epidemiological studies.

(5) Advantages of electronic activity monitoring include accurate estimates of keyboard and mouse use and minimal time commitment for data reduction and analysis. A disadvantage of this method is that such equipment is not commercially available at the present time and thus requires significant technical hardware and software resources for development and implementation. Another disadvantage is that all of the tasks to be monitored must be identified ahead of time for appropriate instrumentation to be developed and implemented. Also, as with work sampling, this method will miss work activities outside the zone of activity monitoring.

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REFERENCES

1. **Faucett, J., and D. Rempel:** VDT-related musculoskeletal symptoms: Interactions between work posture and psychosocial work factors. *Am. J. Ind. Med. 26*:597–612 (1994).
2. **Hales, T.R., S.L. Sauter, M.R. Peterson, et al.:** Musculoskeletal disorders among visual display terminal users in a telecommunications company. *Ergonomics 37*:1603–1621 (1994).
3. **Sauter, S.L., L.M. Schleifer, and S.J. Knutson:** Musculoskeletal discomfort and ergonomic predictors in VDT data-entry work. In S.S. Asfour, editor, *Trends in Ergonomics/Human Factors IV* (pp. 175–185.). Amsterdam, The Netherlands: Elsevier Science Publishers, 1987.
4. **Armstrong, T.J., P. Buckle, L.J. Fine, et al.:** A conceptual model for work-related neck and upper-limb musculoskeletal disorders. *Scan J. Work Environ. Health 19*:73–84 (1993).
5. **National Institute for Occupational Safety and Health (NIOSH):** *A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back.* Cincinnati, Ohio: NIOSH, 1997.
6. **Armstrong T.J.:** Control of upper-limb cumulative trauma disorders. *App. Occup. Environ. Hyg. 11*:275–281 (1996).
7. **National Institute for Occupational Safety and Health (NIOSH):** *A National Strategy for Occupational Musculoskeletal Injuries: Implementation Issues and Research Needs* (NIOSH Pub. no. 93-101). Cincinnati, Ohio: NIOSH, 1992.
8. **Bongers, P.M., C.R. de Winter, M.A.J. Kompier, and V.H. Hildebrandt:** Psychosocial factors at work and musculoskeletal disease. *Scan. J. Work Environ. Health 19*:297–312 (1993).
9. **Bergqvist, U., B. Knave, M. Voss, and R. Wibom:** A longitudinal study of vdt work and health. *Int. J. Human-Computer Interaction 4*: 197–219 (1992).
10. **National Institute for Occupational Safety and Health (NIOSH):** *Health Hazard Evaluation Report, Los Angeles Times* (HETA 90-013-2277). Cincinnati, Ohio: NIOSH, 1993.
11. **National Institute for Occupational Safety and Health (NIOSH):** *Health Hazard Evaluation Report: Newsday, Inc* (HETA 89-250-2046). Cincinnati, Ohio: NIOSH, 1990.
12. **Duncan, J., and D. Ferguson:** Keyboard operating posture and symptoms in operating. *Ergonomics 17*:651–662 (1974).
13. **Fahrbach, P.A., and L.J. Chapman:** VDT work duration and musculoskeletal discomfort. *Am. Assoc. Occ. Health Nurs. J. 38*:32–36 (1990).
14. **Green, R.A., and C.A. Briggs:** Effect of overuse injury and the importance of training on the use of adjustable workstations by keyboard operators. *J. Occup. Med. 31*:557–562 (1989).
15. **Hünting, W., T. Laubli, and E. Grandjean:** Postural and visual loads at VDT workplaces. I. Constrained postures. *Ergonomics 24*: 917–931 (1981).
16. **Kamwendo, K., S.J. Linton, and U. Moritz:** Neck and shoulder disorders in medical secretaries, part 1. Pain prevalence and risk factors. *Scan. J. Rehab. Med. 23*:127–133 (1991).
17. **Knave, B.G., R.I. Wibom, M. Voss, L.D. Hedström, and U. Bergqvist:** Work with video display terminals among office employees, I. Subjective symptoms and discomfort. *Scand. J. Work Environ. Health 11*:457–466 (1985).
18. **Kukkonen, R., T. Luopajarvi, and V. Riihimaki:** Prevention of fatigue amongst data entry operators. In T.O. Kvalseth, editor, *Ergonomics of Workstation Design*. London: Butterworths, 1981.
19. **Maeda, K., W. Hünting, and E. Grandjean:** Localized fatigue in accounting- machine operators. *J. Occup. Med. 22*:810–816 (1980).
20. **Onishi, N., K. Sakai, and K. Kogi:** Arm and shoulder muscle load in various keyboard operating jobs of women. *J. Human Ergol. 11*: 89–97 (1982).
21. **Starr, S.J., C.R. Thompson, and S.J. Shute:** Effects of video display terminals on telephone operators. *Human Factors 24*:699–711 (1982).
22. **Gerr, F., M. Marcus, and D.J. Ortiz:** Methodological limitations in the study of video display terminal use and upper extremity musculoskeletal disorders. *Am. J. Ind. Med. 29*:649–656 (1996).
23. **Hagberg, M.:** Exposure variables in ergonomic epidemiology. *Am. J. Ind. Med. 21*:91–100 (1992).
24. **Foreman, P.:** VDTs in the workplace. *Job Safety Health Quart. 4*:11–12 (1990).
25. **National Institute for Occupational Safety and Health (NIOSH):** *National Occupational Research Agenda: Update, 1997* (NIOSH Pub. no. 97-138). Cincinnati, Ohio: NIOSH, 1997.
26. **Punnett, L.:** Work-related musculoskeletal disorders in computer keyboard operation. In S.L. Gordon, S.J. Blair, and L.J. Fine, editors, *Repetitive Motion Disorders of the Upper Extremity* (pp. 43–48). Rosemont, Ill.: American Academy of Orthopaedic Surgeons, 1995.
27. **Heyer, N., H. Checkoway, W. Daniell, S. Horstman, and J. Camp:** Self-reported musculoskeletal symptoms among office video display terminal operators. In H. Sakurai, editor, *Occupational Epidemiology* (pp. 255–258). Amsterdam, The Netherlands: Elsevier Science Publishers, 1990.
28. **Rossignol, A.M., E.P. Morse, V.M. Summers, and L.D. Pagnotto:** Video display terminal use and reported health symptoms among Massachusetts clerical workers. *J. Occup. Med. 29*:112–118 (1987).
29. **Faucett, J., and D. Rempel:** Musculoskeletal symptoms related to video display terminal use. An analysis of objective and subjective exposure estimates. *Am. Assoc. Occup. Health Nurs. J. 44*:33–39 (1996).
30. **Niebel, B.W.:** Work sampling studies. In *Motion and Time Study,* 9th ed. (pp. 629–667). Homewood, Ill.: Irwin, 1992.
31. **Richardson, W.J., and E.S. Pape:** Work sampling. In G. Salvendy, editor, *Handbook of Industrial Engineering*. New York: John Wiley & Sons, 1992. pp. 4.6.1–4.6.21.
32. **Rockwell, T.H.:** Safety performance measurement. *J. Ind. Engin. 10*: 12–16 (1959).
33. **Franzblau, A., T. Armstrong, R. Werner, et al.:** "A Study of Upper Extremity Musculoskeletal Disorders Among Keyboard Users." Paper presented at the Marconi Computer Input Device Research Conference, Marshall, Calif., Jan. 4–7, 1996.
34. **Franzblau, A., D. Flaschner, J.W. Albers, S. Blitz, R. Werner, and T. Armstrong:** Medical screening of office workers for upper extremity cumulative trauma disorders. *Arch. Environ. Health 48*:164–170 (1993).
35. **National Instruments Corp.:** *LabVIEW 3.1.1* (computer software). Austin, Tex.: National Instruments Corp., 1995.
36. **Stata Corp.:** *STATA 5.0*. College Station, Tex.: Stata Corp., 1997.
37. **Kelsey, J.L., W.D. Thompson, and A.S. Evans:** In *Methods in Observational Epidemiology*. New York: Oxford University Press, 1986. pp. 285–308.

APPLIED STUDIES