Daily Self-Reports Resulted in Information Bias When Assessing Exposure Duration to Computer Use

Che-hsu (Joe) Chang, ScD, PT,[1,2] Cammie Chaumont Menéndez, PhD,[3] Michelle M. Robertson, PhD, CPE,[2] Benjamin C. Amick III, PhD,[4,5] Peter W. Johnson, PhD,[6] Rosa J. del Pino, PT,[5] and Jack T. Dennerlein, PhD[1,7]*

Background *Self-reported exposure duration to computer use is widely used in exposure assessment, and this study examined the associated information bias in a repeated measures setting.*
Methods *For 3 weeks, 30 undergraduate students reported daily cumulative computer-use duration and musculoskeletal symptoms at four random times per day. Usage-monitor software installed onto participant's personal computers provided the reference measure. We compared daily self-reported and software-recorded duration, and modeled the effect of musculoskeletal symptoms on observed differences.*
Results *The relationships between daily self-reported and software-recorded computer-use duration varied greatly across subject with Spearman's correlations ranging from −0.22 to 0.8. Self-reports generally overestimated computer use when software-recorded durations were less than 3.6 hr, and underestimated when above 3.6 hr. Experiencing symptoms was related to a 0.15-hr increase in self-reported duration after controlling for software-recorded duration.*
Conclusions *Daily self-reported computer-use duration had a weak-to-moderate correlation with software-recorded duration, and their relationship changed slightly with musculoskeletal symptoms. Self-reports resulted in both non-differential and differential information bias.* Am. J. Ind. Med. 53:1142–1149, 2010. *© 2010 Wiley-Liss, Inc.*

KEY WORDS: exposure assessment; musculoskeletal disorders; computer use; self-report

INTRODUCTION

The prevalence of upper extremity musculoskeletal disorders is high among computer users (often reported as 50–60%) [Bergqvist et al., 1995; Katz et al., 2000; Schlossberg et al., 2004; Eltayeb et al., 2007]; and prolonged computer use is the most consistently reported risk factor [Gerr et al., 2006; IJmker et al., 2007]. The increased risk

[1]Department of Environmental Health, Harvard School of Public Health, Harvard University, Boston, Massachusetts
[2]Liberty Mutual Research Institute for Safety, Hopkinton, Massachusetts
[3]Center for Disease Control and Prevention, Morgantown, West Virginia
[4]The Institute for Work and Health, Toronto, Canada
[5]School of Public Health, The University of Texas Health Science Center at Houston, Houston, Texas
[6]Department of Environmental and Occupational Health Sciences, School of Public Health & Community Medicine, University of Washington, Seattle, Washington
[7]Department of Orthopaedic Surgery, Brigham and Women's Hospital, Harvard Medical School, Boston, Massachusetts

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*Correspondence to: Jack Dennerlein, Harvard School of Public Health, 665 Huntington Avenue, Boston, MA 02115. E-mail: jax@hsph.harvard.edu

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associated with long computer-use duration has been demonstrated in different populations including workers and college students [Katz et al., 2000; Chang et al., 2007], but the exposure–response relationship has yet to be fully understood due in large part to the difficulty of measuring exposure duration [Homan and Armstrong, 2003].

Data on computer-use duration are often collected using self-reports because of the ease and low cost of survey administration [Gerr et al., 2002; Schlossberg et al., 2004]; however, previous data from cross-sectional studies have reported a moderate Spearman's Correlation value of 0.51 between self-reports and a software-based reference measure, and posed questions regarding to the validity of exposure assessment relying on self-report [Faucett and Rempel, 1996; Mikkelsen et al., 2007]. Self-reports are found to overestimate computer-use duration such that the magnitude of overestimation was larger at shorter durations and smaller at longer durations [Mikkelsen et al., 2007]. If not taken into account, the inconsistent information error in exposure assessment can bias epidemiologic findings.

While previous research has studied self-reports based on one cross-sectional measurement per individual, information bias has not been examined for multiple measurements taken at temporally adjacent time points, which is hypothesized to reduce the bias [Barrero et al., 2008]. Because the information bias of self-reports is a result of recall error, it is suspected that when an individual reports computer-use duration more frequently, recall error might be reduced due to the shorter time lag between exposure and report. In addition, the user is repeatedly and frequently reminded to pay attention to their computer-use duration. Taking more measurements might also improve the accuracy of estimating the average and variability of exposure within a time window.

Therefore, we conducted a field observational study comparing self-reports collected at multiple times a day to daily computer-use duration measured with a validated reference measure, usage-monitor software [Blangsted et al., 2004; Chang et al., 2008]. Within a small pilot cohort, we described the information bias of self-reports and explored the hypothesis that musculoskeletal symptoms are related to changes in the information bias.

METHODS

In the Spring 2004 academic semester, a convenience sample of 30 undergraduate students (15 males and 15 females, age $20.7 \pm$ SD 1.5 years) from a single dormitory was recruited through flyers and E-mails into a repeated-measures observational study. Daily computer-use duration was measured simultaneously using two methods, self-report and computer usage-monitor software (usage-monitor), over three 1-week periods, occurring at the beginning, middle, and end of the school semester. The participants reported their daily cumulative computer-use duration multiple times a day via hand-held computers. The questionnaire was designed to take 2 min to answer, and participants on average answered four questionnaires a day for a total of 8 min estimated spent responding to the questionnaire (Menéndez et al., 2007). This time was not included as computer-use duration. A usage-monitor installed onto each participant's personal computer continuously recorded their computer-use duration throughout the study period, and provided corresponding reference measures temporally for daily computer-use duration. This study was a part of a larger longitudinal study examining different exposure assessment methods related to computer use, posture, and musculoskeletal symptoms [Chang et al., 2007; Menéndez et al., 2007, 2008]. All participants provided consent. The participating university's Institutional Review Board and the University of Texas at Houston Health Science Center Committee for the Protection of Human Subjects approved the study protocol.

Data Collection

The study included a 20-min baseline survey followed by 3-week long data collection periods. The baseline survey was administered to obtain information about demographics and the history of musculoskeletal health. Data used in this study included the participants' responses to the questions "What is your gender" and "In the past 2 weeks, have you experienced pain/discomfort, numbness, tingling, or other pain/discomfort in your hands, wrists, arms, shoulders, or neck when you use a computer?" The responses for these questions were dichotomous (i.e., male/female and yes/no).

During the 3 weeks of data collection, self-report surveys were administered electronically using a hand-held computer carried by each participant. The hand-held computer prompted the participant with audio signals at 10 random times each day. Upon prompting and when available the participant completed the electronic survey on the hand-held computer, which consisted of two major components: first the musculoskeletal symptoms and then daily computer use. Each self-report required approximately 2 min to complete. The daily computer-use component included the questions "For how many hours have you been using your personal computer today" and " For how many hours have you been using another computer today?" The response levels started from 0 hr with 0.5-hr increments of increase. The musculoskeletal symptom component first asked "Are you currently experiencing symptoms?" If yes, then the component continued with the question "How much pain are you now experiencing on a specific body part?" for the 13 different body parts including the neck, shoulders, upper arms, elbows, lower arms, wrists, and hands with the right and left sides distinguished from each other. The response levels included none, mild, moderate, severe, and very severe. For the purpose of data analysis, the 13 body parts in each symptom report were afterwards collapsed into a single variable with two levels of response: symptomatic (reporting moderate, severe, or very severe for any of the body parts) and asymptomatic.

During data collection, usage-monitor software was installed onto the participants' personal computer (denoted by the participant, one computer per participant) to continuously measure computer-use duration (i.e., the software-recorded duration). Most participants (n = 27, 90%) reported that they use their personal computer for at least 90% of their computing time during data collection. The software recorded the date, time, and duration of input device activities, including keyboard keystrokes, pointing device movements, and button clicks with millisecond accuracy [Chang et al., 2004]. Computer-use duration was calculated as the summed duration of all input device activities plus the summed duration of each inactivity period that took place between input device activities and lasted for less than 60 s [Blangsted et al., 2004; Chang et al., 2008]. For each self-report survey completed by the participants, we calculated corresponding daily computer-use duration from usage-monitor data within the time window starting from 06:00 AM in the same morning to the time when the self-report was completed. At 6 o'clock in the morning was defined as the beginning of a day based on the lifestyle reported by the participants prior to the study and verified by inspecting the usage-monitor data, which usually showed no computer use within a 4-hr window around this time.

Data Analysis

Multiple daily self-reported data points were collected from each participant every day during the three 1-week data collection period. Each reported point consisted of a value of self-reported daily cumulative computer-use duration for the day and a dichotomous measure of musculoskeletal symptom. A corresponding value of daily software-recorded cumulative computer-use duration was associated with each self-reported data point. To describe the distribution of the data, we calculated medians of the daily self-reported and software-recorded computer-use duration and the differences between the two measures within each participant and across all participants.

To describe the information bias of daily self-reported computer-use duration, data were first stratified by participant, and we calculated the Spearman's correlation coefficient and fit a simple straight line between the self-reported (the outcome variable) and software-recorded (the predictor variable) duration for each participant. Spearman's correlation was chosen to describe the strength of relationship as the distribution of the data deviated from normal. The straight line fit using linear regression was chosen to describe the pattern of relationship between the self-reported and software-recorded durations in terms of providing a slope and intercept descriptive parameters. Graphical inspection of the data for each participant indicated a linear relationship was suffice, especially for those with high correlations. The data were stratified across participants because preliminary analysis suggested that the relationship between daily self-reported and software-recorded computer use was different across participants. This preliminary analysis was performed using a mixed-effect model (JMP 7; SAS Institute, Cary, NC). The daily self-reported computer-use duration was set as the outcome variable. The predictor variables were software-recorded duration as a fixed effect, participant code as a random effect, and duration by participant interaction. This analysis demonstrated that the effect of participant and the interaction between participant and software-recorded duration were statistically significant predictors ($P < 0.01$ for both).

To compare daily self-reported and software-recorded computer-use duration across participants, we compared each participant's median daily self-reported computer-use duration and median daily software-recorded duration. Each participant represented a data point (i.e., 30 data points). From these 30 data points, we calculated a Spearman's correlation coefficient.

We assessed how the information bias of self-reports changed with daily computer-use duration by modeling the difference between each pair of corresponding daily self-reported and software-recorded duration (software-recorded duration subtracted from self-reported duration) as a linear function of daily software-recorded duration. Similarly, a straight line was fitted using linear regression for the data collected with the self-reported (the outcome variable) and software-recorded (the predictor variable) duration from each participant, and the R^2, slopes and intercepts were reported.

Effects of Musculoskeletal Symptoms, Time Into the Semester, and Using Multiple Computers

To test the hypothesis that the information bias of daily self-reported computer-use duration changes with the status of musculoskeletal symptoms, the Wilcoxon rank sum test was used to compare individual participants' Spearman's correlations (self-reported vs. software-recorded daily duration) between groups of participants divided on three different criteria: experiencing symptoms after computer use within 2 weeks before baseline survey (yes n = 19 vs. no n = 11), reporting symptomatic in more than 4% of all symptom reports (>4% n = 15 vs. ≤4% n = 15) and gender [Chang et al., 2007]. The cut point was chosen to achieve nearly equal numbers of participants in the divided groups.

Mixed effect models described in this paragraph were used to test three separate hypotheses: the relationship between daily self-reported and software-recorded computer-use duration changes with (1) the status of musculoskeletal symptom, (2) time into semester, and (3) using multiple computers. Daily self-reported computer-use duration was modeled as a function of software-recorded duration (fixed effect), participant (random effect), and the interaction between these two predictor variables. We then tested the effect of three cross-over factors by introducing each of them separately as an additional fixed effect predictor into the model. These cross-over factors included reporting as symptomatic by self-report, study period (beginning, middle, and end of semester), and reporting more than 1 hr of computer use on other unmeasured computers on the same day. The three grouping factors listed in the last paragraph (gender, reporting symptoms at baseline, and reporting symptoms during study period) were also examined by introducing each of them separately into the mixed effect model as a predictor in which the participants were nested (i.e., nested factors). Statistical significance was set at the level of 0.05 for all analyses.

RESULTS

A total of 2,132 self-reports were collected from 30 participants during the three 1-week data collection periods (averaging four reports per day per participant). On average, we collected 71 self-reports from each participant (ranging 37–135 reports). Ninety-six percent (96%) of the self-reports were collected on a day during which more than one self-report was completed, and most self-reports (89%) were completed between noon and midnight. The median daily self-reported computer-use duration for a participant ranged from 1.0 to 5.0 hr across participants (median 2.0 hr), whereas the median software-recorded duration ranged from 0 to 1.89 hr across participants (median 0.43 hr). The median daily self-reported durations were 0.9–4.6 hr longer than the median daily software-recorded durations across participants (median 1.9 hr longer).

The Spearman's correlation between daily self-reported and software-recorded computer-use duration ranged from −0.22 to 0.8 across participants (median 0.53, Fig. 1). When each participant was treated as a single data point, emulating a cross-sectional study, the Spearman's correlation between the participants' median daily self-reported duration and median daily software-recorded duration was 0.33.

The linear regression models predicting daily self-reported duration from the software-recorded duration exhibited a common pattern across participants, in which the slopes ranged between 0 and 1, and the intercepts were larger than 0, for 26 participants (87% of the participants). The R^2 values for these fitted models ranged from 0.01 to 0.51 hr across participants (median 0.317). The data did not graphically suggest any form of nonlinear relationship.

The difference between daily self-reported and software-recorded computer-use duration was linearly related to daily software-recorded computer-use duration with a negative slope and positive intercept for 29 participants (97% of all participants, Figs. 2 and 3). The R^2 values for these fitted models were >0.4 for half of the participants. When all data points were combined and each self-report was treated as an independent observation, the general trend was [Difference] = 2.26 hr −0.63*[Software-recorded], $R^2 =$ 0.36. In this overall model, the predicted difference would be 0 when software-recorded duration was 3.6 hr.

The Spearman's correlations between daily self-reported and software-recorded computer-use duration were not different between participants grouped by reporting symptoms at baseline, reporting symptoms during study period, or gender ($P > 0.14$ for any of the Wilcoxon rank sum tests).

After adjusting for daily software-recorded computer-use duration, reporting moderate, severe, or very severe symptoms for at least a body part at the time of a self-report was associated with a small but significant increase in daily self-reported computer-use duration (+0.15 hr, $P < 0.01$) when compared to self-reports with no or mild symptoms (Table I). Meanwhile, using other computers longer than 1 hr on the same day was associated with a small decrease in daily self-reported computer-use duration on the personal computer (−0.1 hr, $P < 0.01$). Study period or reporting symptom at baseline survey was not associated with changes in daily self-reported computer-use duration.

There were three participants whose self-reported duration was negatively correlated with software-recorded duration. To examine the effect of these potential outliers, we also completed all analyses without these three participants (n = 27), and the results remained similar.

DISCUSSION

The goal of this study was to describe the information bias of daily self-reported computer-use duration based on comparisons with a validated reference measure, usage-monitor software. Daily self-reported durations of computer use generally increased with software-recorded durations; however, self-reports were likely to overestimate short durations of daily computer use while underestimate long ones. Reporting musculoskeletal symptom at the time of self-report was associated with a small increase in daily self-reported computer-use durations, and using multiple computers was associated with a small decrease in self-reported computer use on the personal computer.

Information bias in the exposure duration to computer use due to self-report was more pronounced in between-individual exposure comparisons than within-individual comparisons. The nonparametric correlations between self-reported and software-recorded computer use were moderate

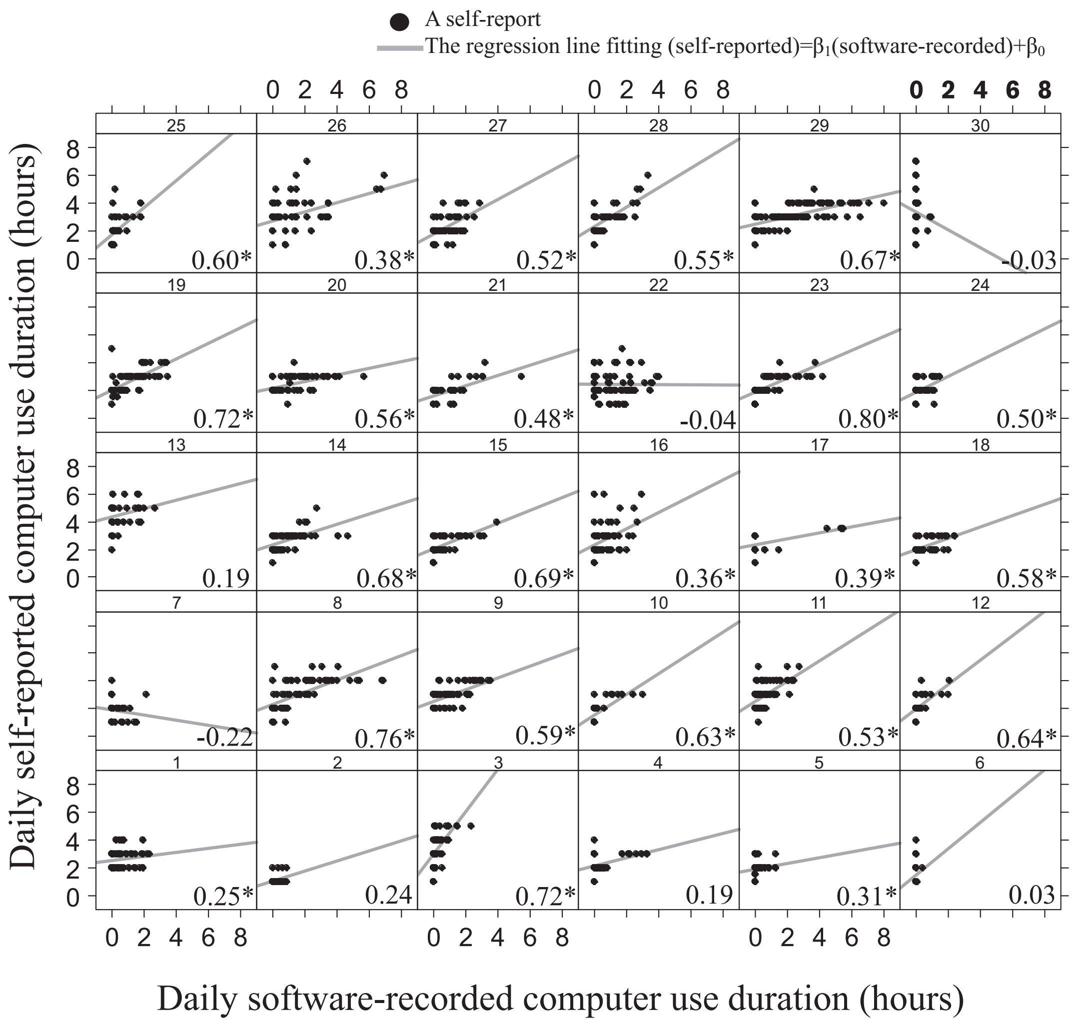

FIGURE 1. The distribution, Spearman's correlation, and linear regression line between daily self-reported and software-recorded computer-use duration for each of the 30 participants. Each cell represents a single participant. The regression lines were plotted to illustrate the different slopes and intercepts across participants. On average, 71 observations were made for each participant for a total of 2,136. *$P < 0.05$ testing Spearman's correlation different from 0.

for about one-third of the participants, suggesting that self-reports provided some capability of comparisons across data points repeatedly measured from an individual over time. However, when computer-use duration was compared across individuals, self-reports were in poor agreement with software-recorded computer use. Administering self-reports multiple times a day did not appear to yield valid estimates of exposure duration consistently. While exposure in epidemiologic studies is often classified into categorical levels, misclassification resulting from self-reported exposure could be substantial due to the insufficient correlation between self-reported and directly measured (i.e., software-recorded in this present study) exposure.

In addition to suboptimal exposure classification, self-reports also biased the numeric values of exposure inconsistently, which can be critical when one models exposure–response relationships. First, the linear relationship between daily self-reported and software-recorded computer-use duration demonstrated that an hour increase in software-recorded duration was associated with less than an hour increase in self-report. As a result, self-reports diminished the difference between values of computer-use duration by more than 50% (i.e., slope <0.5) for half of the study cohort (15 participants). Second, self-reports were likely to overestimate daily software-recorded computer-use duration when the duration was shorter, and, to underestimate software-recorded duration when the duration was longer. The cut point between overestimation and underestimation ranged from 1 to 8 hr of daily computer use across participants. Therefore, a mixture of overestimation and underestimation can occur when daily computer use varies around the cut point.

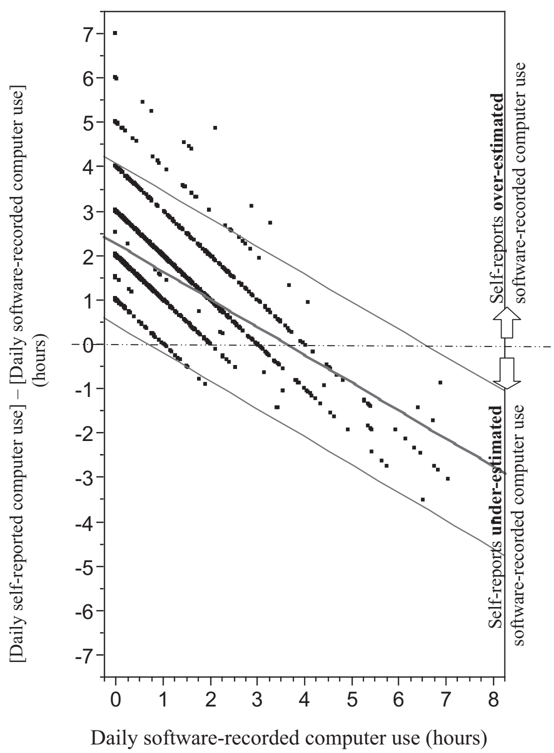

FIGURE 2. The relationship between daily software-recorded computer use and the differences between daily self-reported and software-recorded computer-use duration. To present the overall trend, the linear regression line and 95% prediction confidence interval showed in this plot was based on all data points treated as independent observations.

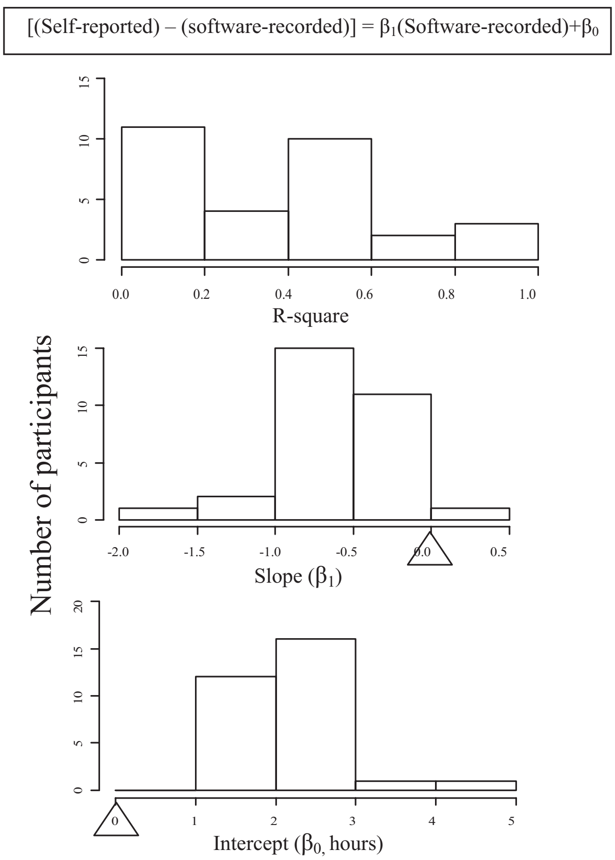

FIGURE 3. The distribution across the 30 participants for the R^2 values, slopes, and intercepts of the linear regression fitting the difference between daily self-reported and software-recorded computer-use duration as a function of daily software-recorded computer-use duration. The triangle indicates the zero when possible values can vary around 0.

While we observed both overestimation and underestimation in self-reported computer-use duration, previous studies reported only overestimation [Faucett and Rempel, 1996; Mikkelsen et al., 2007]. It has to be noted that previous studies were cross-sectional in design, and our study was a repeated-measures design. Analogous to a cross-sectional design, when we examined a single summary statistics (e.g., median) calculated based on all data points collected from an individual, self-reports then consistently overestimated software-recorded durations for all individuals in this cohort. However, when multiple data points were

TABLE I. The Effect of Cross-Over and Nested Factors in the Relationship Between Daily Self-Reported and Software-Recorded Computer-Use Duration for the 2,132 Self-Reports From the 30 Participants

	Parameter estimate	*P*-value
Cross-over factors		
Reporting moderate or severe symptom at the time of hand-held computer self-report (246 reports, 11.5% of all reports)	0.15	<0.01*
Study period (each period consisted of roughly one-third of all reports)	Middle = Beginning—0.08, End = Beginning—0.03	0.06
Using another computer >1 hr within the same day as hand-held computer self-report (407 reports, 19% of all reports)	−0.10	<0.01*
Nested factors		
Gender (15 males, 50% of the cohort)	0.12	0.62
At baseline: experience symptoms after computer use (19 students, 63% of the cohort)	−0.16	0.18
Reporting symptoms in more than 4% of the reports (15 students, 50% of the cohort)	0.03	0.77

*$P < 0.05$.

collected and examined for each individual, daily durations were then biased towards a value within the range of these daily self-reported durations. The underlying mechanism is unclear, but the difference in study cohort (office workers vs. undergraduate students) and sampling strategy (one-time measure vs. repeated measures over time) might have changed how individuals recalled their computer use.

The information bias observed in this study could be a result of recall error or misunderstood definitions of computer use. While computer use was estimated from usage-monitor data by including inactivity periods less than 60 s to capture passive computing activities (such as reading web contents on computer monitor) [Chang et al., 2008], the participants might have defined computer use otherwise. For example, participants might have included time when reading a textbook at their computer workstation, hence the large observed overestimation. The consequent non-differential exposure misclassification (errors independent of the status of disease) can possibly bias findings on exposure–response relationship towards or away from the null hypothesis [Jurek et al., 2008].

Self-reports could also result in differential information bias as we observed an error in exposure estimate associated with the status of musculoskeletal symptoms. For a given individual, experiencing musculoskeletal symptoms at the time of a self-report was statistically related to an increase in daily self-reported computer use after adjusting for software-recorded duration. The observed differential information error could possibly bias the exposure–response relationship away from the null hypothesis because an individual was more likely to report longer daily computer use when experiencing symptoms. The magnitude of this systematic error in this cohort was, however, small (0.15 hr); and, its impact in an epidemiologic study has to be determined by the distribution of the data and the design of the study.

Different patterns of non-differential and differential information bias were observed in daily self-reported computer use; and, consequently, it is difficult to conclude the final direction of potential bias (towards or away from the null hypothesis) in exposure–response relationships. In addition, factors associated different cohorts and different occupational environments might further alter the error of self-reports. Therefore, we suggest that the information bias of self-reports needs to be examined before implementation in a specific cohort investigating the relationship between computer use and musculoskeletal disorders.

The fact that we studied undergraduate students might limit generalizing the results. Students need to be studied because they are computer users with high prevalence of computer-related musculoskeletal disorders [Katz et al., 2000; Schlossberg et al., 2004]; however, generalizing our results to working populations needs to account for potential differences in work schedules, lifestyles, and individual factors (e.g., age). In addition, this exploratory study was based on a small sample; however, our results demonstrated that the relationship between daily self-reported and software-recorded computer use was fairly similar across individuals. We would expect similar findings if the data were collected from a larger cohort.

While we expect computer usage-monitor software installed onto personal computers to capture most computing activities, 21 participants reported using other computers at least once during the study period. We installed usage-monitor on only one computer per participant and asked the participant to report computer use on that particular computer. Most participants reported that they used their personal computer for most of their computing time; however, it is still unclear how using multiple computers affected the error of self-reports. Collecting data from all computers used by the participants might help further explain and examine the sources of information bias.

The potential correlation between data points collected within the same day from the same participant and the varying exposure windows are limitations of our analysis. Within a day, daily cumulative computer-use duration collected at a later time was always larger or equal to the duration collected at an earlier time; and, the exposure window for a data point collected at a later time was always longer than that for an earlier data point. Due to the small sample size, the analysis was not consolidated into a single model to control for the correlation or exposure window; however, these limitations only prevented us from further explaining the potential sources of information error, but did not compromise the purpose of this study, to explore the relationship between self-reported and software-recorded daily computer use.

The primary strength of this study was that data points from each individual were collected over the course of several weeks to capture temporal changes in computer use. The data were collected at different times throughout a school semester, accounting for the longer cycle of a student cohort's work (i.e., study) and lifestyle. The week-long consecutive data then accounted for the variability in computer use within a week. Finally, multiple self-reports were collected every day to capture the variability within a day.

In conclusion, this exploratory study demonstrated that daily computer-use duration self-reported multiple times a day was weakly to moderately correlated with the corresponding duration measured by computer usage-monitor software. The information bias associated with self-reports exhibited both non-differential and differential characteristics, which could bias epidemiologic findings towards or away from the null hypothesis. Our findings along with previous evidence in the literature suggest that better understanding of self-report data as well as their relationships with specific outcomes is needed to understand the complex nature of these metrics in exposure assessment [Barrero et al., 2009].

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