A Wide Range of Activity Duration Cutoffs Provided Unbiased Estimates of Exposure to Computer Use

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A Wide Range of Activity Duration Cutoffs Provided Unbiased Estimates of Exposure to Computer Use

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Integrative computer usage monitors 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. 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. 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. It is concluded that activity duration cutoffs ranging from 28 to 60 sec provided unbiased estimates of computer use duration.

Keywords   exposure assessment, computer use, validity, usage-monitor software

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INTRODUCTION

The most consistently identified risk factor for computer-related musculoskeletal disorders (MSDs) is prolonged computer use.[1] Different methods have been used to assess exposure duration to computer use in epidemiologic studies, and self-reports were the most widely used.[2−4] However, self-reports are found to overestimate computer use durations and might bias epidemiologic results linking computer use and MSDs.[5,6]

In the last decade, integrative computer usage monitor software (usage-monitors) have been developed and used by researchers[7,8] and commercial companies as a direct measure to quantify computer use. Usage monitors can automatically record temporal information of computer input device activity over long periods of time without field instrumentation; one needs only to load software on the worker's existing computer. Ease of implementation and versatility make these programs quite suitable for data collection in large cohorts.

Although usage monitors precisely record the duration of input device activity such as keystrokes,[9] pointing device movements, and button clicks, they cannot directly measure the user's passive computing activity, such as viewing and reading the visual display of the computer (i.e., computer monitor). Capturing these passive activities is important in determining the duration of certain exposure parameters, such as static loading,[10] posture,[11] and work-rest patterns.[12]

Typically, from usage monitor data, passive computing activities are captured as the summed duration of inactivity periods that take place between input device activities and are shorter than a predetermined activity duration cutoff. This summed duration is then added with the duration of each input device activity to estimate the total duration of exposure to computer use. Activity duration cutoffs reported in the literature are usually either 30 or 60 sec.[8,13] Although Blangsted et al.[13] reported a high correlation (Pearson's correlation 0.93-0.94) between computer use durations obtained from video recordings and durations obtained from a usage monitor using a 30-sec cutoff, the validity of other cutoff values has not been investigated.

The goal of this study was to systematically examine and compare the validity across a wide spectrum of activity duration cutoffs used with usage monitors to estimate computer use duration. Validity of the estimated duration was determined

by comparisons with computer use observed from video recordings.

METHODS

A convenience sample of 20 office workers (36 ± 9 years old, 7 males and 13 females) was recruited through flyers and e-mails in a university to participate in this observational field study. Among the participants, 70% were administrative staff and 30% were research staff. All participants reported using their computer more than half of their normal work hours prior to participation. Eighty-five percent and 15% of the participants used desktop and laptop computers, respectively. Ninety percent of the participants used an external mouse as the pointing device, and 10% used a touch pad. For each participant, computer use duration was measured simultaneously by video recording and a usage monitor for 4 consecutive hours on a typical workday. To collect enough data on computer use, a workday was chosen when the participant anticipated not being away from their workstation for more than 1 continuous hour, for example, a scheduled 1-hr meeting, during the 4-hr data collection. The study protocol was approved by the Human Subjects Committee at the Harvard School of Public Health.

Video Recording

Computer use duration was observed from video recordings of each participant's work; this observed duration served as the reference to determine the validity of the computer use duration estimated with the usage monitor. A video camera (Sony DCR TRV-103; Sony Corporation, Tokyo, Japan) was set up on the side of the participant's workstation such that the view included the participant's face, upper trunk, hands, edge of computer visual display (to confirm its location in the participant's visual field), keyboard, and pointing device as much as possible. Computer use in the video recordings was defined by observational criteria, including typing on keyboard; using pointing device (holding, moving, activating buttons, scrolling or dragging); transferring hands between input devices; poising one or both hands above any input device; and looking toward visual display. The observed computer use duration was defined as the total duration during which any of the aforementioned activities was observed. Video recordings were analyzed by a single trained analyst blinded from the usage monitor data; test-retest reliability was examined by intraclass correlation (ICC) on 10 1-hr video recordings analyzed twice, separated by two weeks (i.e., 10 pairs of data points). The video playback speed was 2.1 times as fast as the original recording speed to reduce the time needed to analyze the video tapes.

Usage Monitor

Computer use duration was estimated from input device activities recorded by a usage monitor installed onto each participant's computer. The usage monitor, programmed in LabVIEW (v. 7.1), recorded the begin and end time of each keystroke, pointing device movement, and button click event,

as well as the durations of inactivity periods occurring between activity events. Computer use duration estimates were calculated as the summed duration of all input device activities plus the summed duration of the inactivity periods that were shorter than a given activity duration cutoff. From each participant's usage monitor data, 238 estimates were calculated using 238 different values as the activity duration cutoff, ranging from 3 to 240 sec in 1-sec increments. In addition, we estimated keyboard and pointing device use durations with the 30-sec cutoff.[13] To describe the distribution of input device use patterns, we calculated the ratio between pointing device use duration and keyboard use duration for each participant.

Validity Analysis

Validity of the estimated computer use duration was examined by within-participant and across-participant comparisons between the observed and estimated computer use durations. In the within-participant comparisons, for each participant, the observed duration was compared with each of the 238 estimates, and the activity duration cutoff that yielded the smallest difference was identified as an individual's specific cutoff value.

In the across-participant comparisons, an average difference and an average relative difference between the observed and estimated durations was calculated for each of the 238 sets of estimates. The difference was calculated by subtracting the observed duration from the estimated duration for each participant; the relative difference was calculated by dividing the difference by the observed duration. Average difference across participants was calculated in two ways, using the original values and absolute values of the differences, between which the latter prevented positive and negative values from canceling out each other.

The Spearman's correlation and Cohen's Kappa coefficient between the observed and estimated computer use durations were calculated for each of the 238 sets of estimates. A nonparametric correlation (the Spearman's correlation) was used because the estimated durations were not normally distributed across participants (Shapiro-Wilk W test, $p < 0.05$). The Kappa coefficients were calculated based on dichotomizing the participants' computer use durations by 2 hr of computer use. Since 4 hr of daily computer use has been related to increased risk of MSDs,[1] and our data collection was roughly a half workday long, the 2-hr cut point was designed to scale the exposure difference between high and low risk when results were extrapolated to a whole day. A higher Kappa coefficient indicated better agreement between the observed and estimated durations, thus, less exposure misclassification.

To compare the linear relationships between the observed and estimated computer use duration across the 238 cutoff values, a simple linear regression model was fit for each cutoff using the least square method. The model was:

$$\text{Estimated duration} = \beta_0 + \beta_1(\text{observed duration}) + e$$

With each participant representing a data point in the model, the predictor variable was the observed duration, and the

predicted variable was the software-estimated duration. The ideal linear relationship was considered as the slope (β_1) equal to one, R-square equal to one and intercept (β_0) equal to zero. The Shapiro-Wilk W test was used to determine whether the residuals of these linear models were normally distributed. Statistical significance level was set at 0.05.

RESULTS

Computer use durations observed from the video recordings ranged from 1.3 to 3.3 hr (mean 2.0 ± S.D. 0.5 hr) across participants during the 4-hr observational period. Test-retest reliability of the video analysis was high (intraclass correlation 0.97). Input device activity data suggested that 85% of the participants used the pointing device longer than the keyboard (Figure 1) with the ratio of pointing device to keyboard use duration ranging from 0.6 to 5.2 (mean 2.1, standard deviation 1.1).

In the within-participant comparisons, the individual specific activity duration cutoffs, which estimated the observed computer use duration with the smallest difference (mean difference 0.003 ± S.D. 0.010 hr across participants), ranged from 15 to 79 sec across participants (Figure 2).

In the across-participant comparisons, the smallest average difference between the observed and estimated durations was 0.01 ± S.D. 0.13 hr (relative difference 0.60% ± S.D. 7.45%) observed at the cutoff value of 38 sec (Figure 3). When the average differences were calculated with absolute values, the smallest was 0.09 hr (relative difference 5.2%) and observed at the cutoff value of 41 sec (Figure 4). The highest Spearman's correlation 0.92 was observed at the activity duration cutoffs of 30, 32, and 33 sec. The Kappa coefficient of dichotomizing the computer use duration by 2 hr was one (i.e., the observed and estimated durations in complete agreement) for cutoff values ranging from 28 to 60 sec (Figure 4). Smaller differences, higher Spearman's correlation, and higher Kappa coefficient indicated better validity.

The linear regression models suggested that the 55-sec activity duration cutoff was associated with the slope closest to one (0.95), and the 28-sec cutoff was associated with the highest R-square value (0.94). The intercepts were small (0.07 hr to 0.26 hr) and not statistically significant (p = 0.09 to 0.78) for the range of 3- to 67-sec cutoffs (Figure 5); and, the residuals were normally distributed for this range of cutoffs (Shapiro-Wilk W test, p = 0.27–0.98).

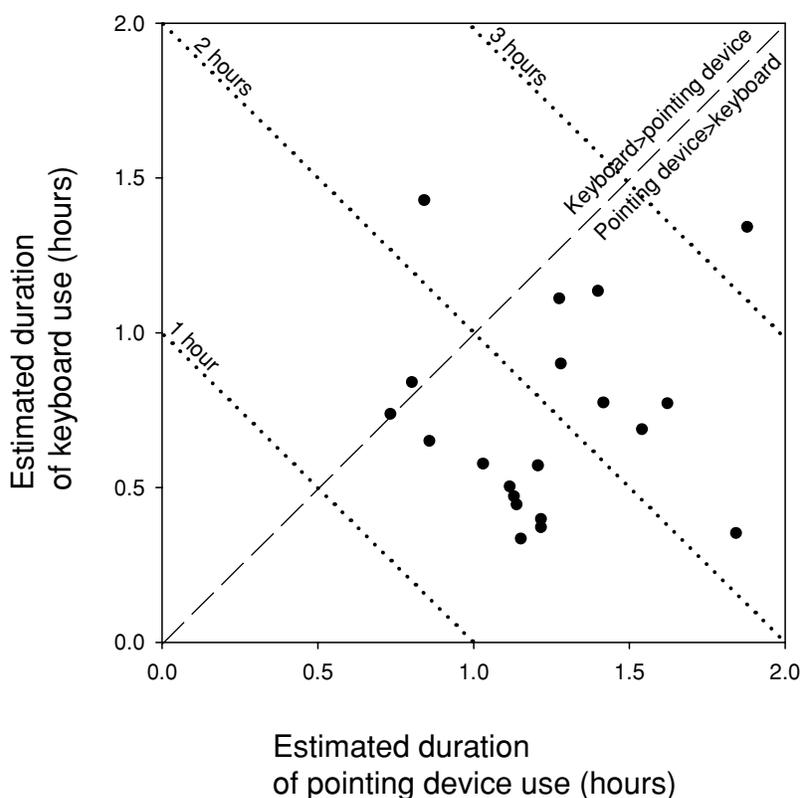Overall, for the range of 28- to 60-sec activity duration cutoffs that were associated with the Kappa coefficient of

FIGURE 1. The estimates of keyboard and pointing device use duration calculated with the 30-sec activity duration cutoff. Each data point represents a participant.
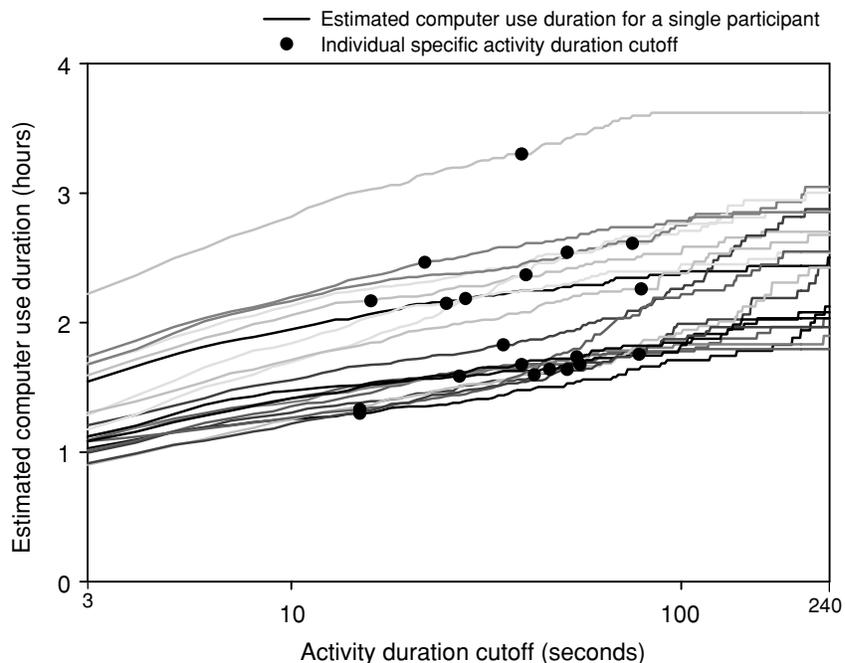
FIGURE 2. The observed and estimated computer use durations for each participant. Each line represents a single participant and shows how the estimates changed with the activity duration cutoff. The black dot on each line represented the observed duration (the orthogonal projection onto the Y axis) for 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.[14]
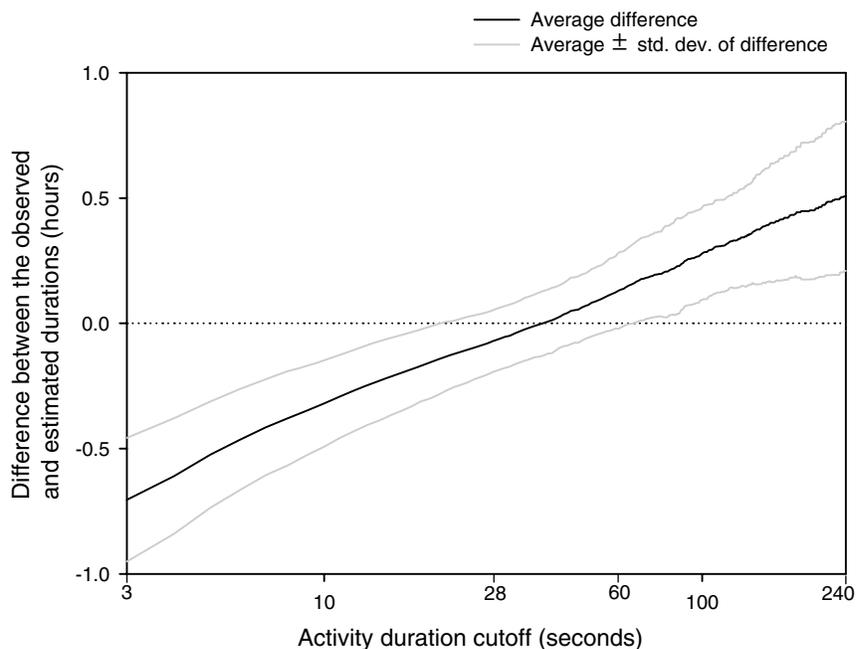

FIGURE 3. The average difference between the observed and estimated computer use durations (difference = estimated − observed) across all participants. The x-axis (activity duration cutoff) is a base ten logarithmic scale. The 28- and 60-sec tick marks are in reference to the results of Figure 4.
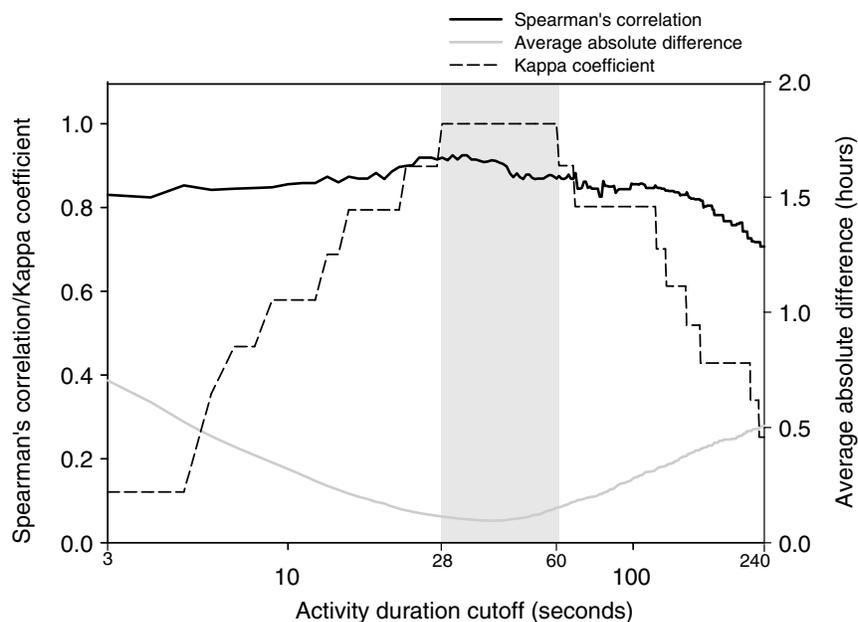
FIGURE 4. The Spearman's correlation, average of the absolute values of the differences between observed and estimated durations, and Kappa coefficient. The x-axis (activity duration cutoff) is a base ten logarithmic scale. The range of 28- to 60-sec cutoffs was associated with Kappa coefficient of one, hence, no observed exposure misclassification.

one, the Spearman's correlation was 0.87 to 0.92, the average differences were –0.07 to 0.13 hr (relative difference –3.16% to 7.44%), the slopes of the linear models were 0.92 to 0.95, the R-square values were 0.91 to 0.94 and the intercepts were 0.10 to 0.24 hr.

DISCUSSION

The goal of this study was to examine and compare the validity of a wide spectrum of activity duration cutoffs used with usage monitors for estimating computer use duration.
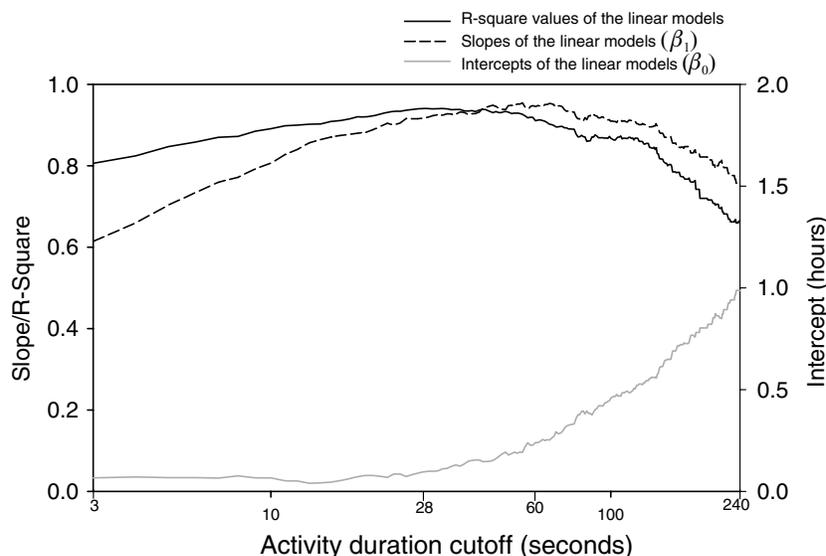

FIGURE 5. The R-squares, slopes, and intercepts of the linear regression models fitting the estimated computer use durations as a function of the observed durations. The ideal model was defined as the R-square equal to one, slope equal to one and intercept equal to zero. The 28- and 60-sec tick marks are in reference to the results of Figure 4.

For cutoff values ranging from 28 to 60 sec, the differences between the observed and estimated durations were small, and the correlations were high. Estimates provided by this range of cutoffs exhibited minimal exposure misclassification and were linearly related to the observed computer use duration with slopes close to one, high R-square values and small intercepts. This wide range of activity duration cutoffs is suggested to estimate computer use duration with good validity in this cohort.

While the activity duration cutoff associated with the best validity at individual level varied over a wide range across participants, using a single cutoff value to estimate everyone's computer use duration resulted in only minimal exposure misclassification. The small differences (i.e., errors) between the observed and estimated durations did not compromise the classification of individuals' exposure levels. Due to the small sample size and short observational period of our study, the exposure misclassification was examined only with the fewest levels (two levels) of exposure duration using a cutoff suggested by the literature.[1] The potential exposure misclassification in a large epidemiologic study should be determined by the distribution of the data and how exposure is classified.

As demonstrated in the regression models between the observed and estimated durations, strong one-to-one linear relationships further confirmed that usage monitors are capable of providing unbiased estimates as well as comparisons among different levels of computer use duration. Although the intercepts of these models within the recommended range of 28- to 60-sec cutoffs were not the smallest across the whole spectrum of cutoff values, they remained small (0.10–0.24 hr) yet statistically insignificant. In addition, intercepts were constant offsets that did not vary with changes in computer use duration and, therefore, would not bias the differences among individuals' computer use durations estimated with usage monitors.

It was difficult to select a single value as the most valid activity duration cutoff because different comparison statistics suggested slightly different cutoff values that maximized the performance of a given statistic. Whereas the performance of the suggested range (28 to 60 sec) was similarly high (Figures 3–5), using a cutoff value smaller than 38 sec might result in slightly more underestimation, and a cutoff value larger than 38 sec might result in slightly more overestimation (Figure 3). Hence, the conclusion of the 28- to 60-sec cutoffs was based on minimal exposure misclassification and, more importantly, emphasize the similarity in the validity for this wide range.

The commonly used 30- and 60-sec cutoffs exhibited similar validity; however, caution should be taken when directly comparing duration data collected in different studies using different activity duration cutoffs. Increasing the activity duration cutoff increases the estimate of computer use duration by including more estimated passive computing activities. In our study, when the activity duration cutoff was increased from 30 sec to 60 sec, software-estimated computer use duration increased correspondingly by 4% to 30% across participants.

A given value of computer use duration estimated using a 30 sec cutoff in a study might indicate a true exposure different from the same value estimated using a 60 sec cutoff in another study, making direct comparisons across studies complicated due to the different cutoffs.[14] Using a unified activity duration cutoff in future studies will help improve the comparability across past and future studies. Therefore, we suggest researchers use a 30-sec cutoff because it has been used in several studies[6,13] and is associated with slightly higher correlation between the observed and estimated durations.

In our study, computer use duration observed from the video recordings was the reference to evaluate the validity of the estimates, and it should be noted that the video analysis was based on criteria of observation but not physical exposure (e.g., posture, force, muscle activity, etc.). Similarly, usage monitor does not provide information about how actual physical exposure varies during computer use. Although physical exposures such as posture have been related to MSDs,[11] it is still unclear how variability in physical exposures is related to the risk of MSDs. With the exposure duration measured by usage monitor, additional information about physical exposure might be needed to construct a comprehensive exposure profile when studying MSDs.[15] Furthermore, integrating usage monitors with task-based exposure estimates[16] may provide information to determine what type of physical factors (e.g., dynamic vs. static loading) is important.

The homogeneity of the study participants' occupations might limit the generalizability of our results. The potential differences in computer use patterns and tasks of different occupations might alter the validity of estimating computer use duration.[14] For example, the computer use pattern of a financial manager who spends most work time reading financial reports on the visual display may be different from that of a graphic designer who constantly interacts with the pointing device during computer use. The activity duration cutoff that accurately estimates the financial manager's computer use duration may be longer than the cutoff for the graphic designer.

In addition, the graphic designer's computer use may involve more pointing device use and less keyboard use when compared with the financial manager. However, a wide range of individual specific cutoffs and a wide range of input device use patterns were observed in our study cohort, suggesting that our findings were based on a variety of different computer use patterns.

The usage monitor in this study did not record the activity of the scroll wheel on the pointing device, and we anticipate that not recording scrolling activities resulted in only a small underestimation of computer use duration. As long as scrolling was bounded by other types of input device activities within the duration of the activity cutoff, it had been included in the estimate of computer use duration. A few events might have been overlooked if they occurred during inactivity periods longer than the activity duration cutoff; however, such error is expected to be small. To completely avoid this shortcoming, future studies are suggested to record scrolling activities.

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.

ACKNOWLEDGMENTS

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