Original article

Scand J Work Environ Health. 2012;38(2):155–162. doi:10.5271/sjweh.3196

Is peak exposure to computer use a risk factor for neck and upper-extremity symptoms?

by Janneke M Richter, PhD,[1] Swenne G van den Heuvel, PhD,[1, 2] Maaike A Huysmans, PhD,[2, 3] Allard J van der Beek, PhD,[2, 3] Birgitte M Blatter, PhD [1, 2]

Richter JM, van den Heuvel SG, Huysmans MA, van der Beek AJ, Blatter BM. Is peak exposure to computer use a risk factor for neck and upper-extremity symptoms? *Scand J Work Environ Health.* 2012;38(2):155–162. doi:10.5271/sjweh.3196

Objective Epidemiologic studies on physical exposure during computer use have mainly focused on average exposure duration. In this study, we aimed to relate periods of high peak exposure during computer use with the occurrence of neck–shoulder (NS) and arm–wrist–hand (AWH) symptoms.

Methods A prospective cohort study among 1951 office workers was carried out for two years, with periodical questionnaires and continuous measurements of computer input use. To define peak exposure, a distinction was made between peak days and weeks. Peak days were defined as days with a long duration of computer (ie, ≥4 hours) or mouse use (ie, ≥2.5 hours) or days with high frequency of mouse (ie, ≥20 clicks per minute) or keyboard use (ie, ≥160 keystrokes per minute). Weeks containing ≥3 peak days were considered peak weeks. Independent variables were numbers of peak days and peak weeks during a 3-month measurement period; dependent variables were self-reported NS and AWH symptoms during the following 3-month measurement period.

Results Valid data were available for 2116 measurements of 774 office workers. No relation was found between any of the peak exposure parameters and AWH symptoms or with peak exposure in duration and NS symptoms. Most parameters referring to high frequency-related peak exposure were associated with less NS symptoms, but the effect estimates were very small and the confidence intervals close to the null.

Conclusion In this study, we found no indication that high peaks in computer use were related to the occurrence of NS or AWH symptoms.

Key terms cohort study; keyboard use; mouse use; office worker; registered computer use.

Extensive computer use is often associated with symptoms of the upper extremity; several reviews have found a positive relation between the duration of computer use and the occurrence of upper-extremity symptoms (1–3). The studies in these reviews estimated the duration of computer use with self-reports or observational techniques. However, it seems that the presence of an association is partly dependent on how computer-use duration was assessed. Studies using more objective methods of assessing computer-use duration have found mixed results. Two recent studies measuring computer-use duration by registration software did not find a relation between duration and the prevalence or incidence of chronic upper-extremity symptoms (4, 5). On the other hand, two studies using registration software did find a relation between the duration of computer use and acute upper-extremity symptoms (4, 6).

So far, epidemiologic studies on physical exposure during computer use have mainly focused on the average duration of exposure (2). However, it is generally acknowledged that when quantifying physical exposure, three dimensions should be considered: (i) amplitude (level, intensity), (ii) frequency (repetitiveness, eg, per second, per day), and (iii) duration (time, eg, seconds, days) of the load (7). We found one study that compared different dimensions of physical exposure in relation to musculoskeletal symptoms. Norman et al (8) analyzed several cumulative and peak-exposure variables as

1 TNO Netherlands Organisation for Applied Scientific Research, Hoofddorp, the Netherlands.
2 Body@Work Research Centre on Physical Activity, Work and Health, TNO-VU/VUmc, Amsterdam, the Netherlands.
3 Department of Public & Occupational Health, EMGO+ Institute for Health & Care Research, VU University Medical Center, Amsterdam, the Netherlands.

Correspondence to: SG van den Heuvel, Postbus 718, 2130 AS Hoofddorp, the Netherlands. [E-mail: swenneke.vandenheuvel@tno.nl]

predictors of reported low-back pain in the automotive industry. They found both types of exposure to predict low-back pain, but also found low correlations between the peak and corresponding cumulative measures of physical exposure. Therefore, they stated that cumulative exposure variables are not simply the values of peak variables multiplied linearly by time and concluded that cumulative and peak exposure measure different aspects of occupational physical exposure (8). They also suggested making a distinction between cumulative loading that is the result of high repetition or the result of prolonged duration because their potential injury-inducing pathways are probably different.

Epidemiologic studies on physical exposure during computer use have, so far, mainly focused on exposure duration and not on the other two dimensions of physical exposure (2, 9). Furthermore, most studies have used the mean duration of computer use, usually averaged over a prolonged period of time (2). The focus on cumulative exposure originates from the Cinderella theory. In this theory, low-force demands during computer use lead to continuous activity of small muscle fibers, presumed to be active all the time. This continuous activity is believed to cause tissue damage over time (10).

However, apart from continuous muscle activity, the lack of recovery time after muscle activity also seems a risk factor for the occurrence of muscle or tissue damage (11–13). Then, it is not so much a high mean exposure of computer use causing damage, but a high number of days with prolonged duration of exposure, implying insufficient recovery time within a day. Another possibility is that, for example, typing very fast or clicking the mouse very frequently could cause musculoskeletal damage, especially if recovery time is insufficient (14, 15). Then, the high number of days with this style of high frequency input device use could be an important risk factor. This coincides with the findings of IJmker et al (5) who recommended using more detailed measures of exposure of computer use in research on musculoskeletal symptoms, such as peak exposure or the absence of variability in exposure.

In this study, we aimed to relate periods of high-peak exposure to the occurrence of neck and upper-extremity symptoms. Occurrence could refer to incidence, recurrence, or persistence of symptoms. We defined high-peak exposure during computer use as the number of days or weeks with either long duration of computer use per day or high input device use.

Our research questions were: (i) is the number of days or weeks with a long duration of computer or mouse use a risk factor for the occurrence of neck and upper extremity symptoms? (ii) is the number of days or weeks with a high frequency of mouse use or keyboard use a risk factor for the occurrence of neck and upper-extremity symptoms?

Methods

Study design

Data were used from the PROMO (prospective research on musculoskeletal disorders in office workers) study, a cohort study with a follow-up of 24 months (16). Assessment of the health outcome took place at baseline and every three months during follow-up using a web-based questionnaire. Exposure data of computer use were collected continuously during the study period by means of a software program. Participation was voluntary and participants signed informed consent forms. The Medical Ethics Committee of the VU University Medical Center approved the study design.

Subjects of the PROMO study

Subjects were recruited from five different companies in the Netherlands with at least 500 office workers: a brewery, a financial consultancy firm, a university, a transportation company, and an insurance company. All included participants had office work as their main job function. Further information on inclusion criteria can be found in IJmker et al (16). In total, 1951 out of 9161 (21%) employees signed informed consent forms and completed the first questionnaire. More details on the characteristics of the participants of the PROMO study are presented in table 1.

Assessment of exposure to computer use

During the two years of the study, data on computer use were collected continuously using the software program WorkPace version 3.0 (Wellnomics Ltd/ErgoDirect, Christchurch, NZ). The program had been installed from the central network on the individual computer of the participants. During the time the subjects were logged on to their computer, the software registered key presses, mouse clicks, and mouse movements (computer input) and stored these parameters as cumulative totals per day. The duration of keyboard, mouse and total computer use were calculated per day. The non-computer threshold (NCT) or time between two consecutive computer events for calculating a period of computer use was 30 seconds, which means that if a subject hits a key, moves, or clicks the mouse within 30 seconds of previous computer input, the time period in between the events is stored as a usage period of total computer use. The threshold value reflects the use of the keyboard or mouse, reading from the screen and performing combinations of these activities. The value was based on previous studies that found that the average duration of total computer use based on WorkPace estimates was within 10% of the average duration of total computer use

Table 1. Main characteristics of the participants in the PROMO study and those included in the analyses. [Pop=poplulation.]

	Brewery		Financial consultancy firm		University		Transportation company		Insurance company		Total	
	PROMO pop (N=162)	Study pop (N=88)	PROMO pop (N=186)	Study pop (N=94)	PROMO pop (N=413)	Study pop (N=108)	PROMO pop (N=423)	Study pop (N=109)	PROMO pop (N=767)	Study pop (N=375)	PROMO pop (N=1951)	Study pop (N=774)
	Mean %	Mean %	Mean %	Mean %	Mean %	Mean %	Mean %	Mean %	Mean %	Mean %	Mean %	Mean %
Age	40	41	35	36	41	41	42	42	40	41	40	40
Men	56	58	44	34	37	35	60	63	57	58	52	53
Women	44	42	56	66	63	65	40	37	43	42	48	47
Neck or shoulder symptoms (baseline)	25	26	28	28	27	24	26	28	27	28	27	27
Arm, wrist or hand symptoms (baseline)	20	23	17	15	21	19	15	11	17	18	18	17

based on systematic observation (17, 18). The NCT for calculating a period of mouse use was 5 seconds and 2.5 seconds for keyboard use. The three different thresholds for total computer, keyboard, and mouse use reflect the fact that total computer time is not merely the sum of mouse and keyboard duration.

Calculation of parameters for peak computer use

Each measurement period had a duration of three months and ended with a questionnaire. Within each measurement period, peak exposure during computer use was operationalized using several parameters. Some of the parameters were used as a daily measure for peak computer use, while others were calculated as a weekly measure for peak computer use. For each measurement period, we calculated in total eight computer parameters in two dimensions: four parameters in the "duration" dimension and four parameters in the "frequency" dimension.

In the "duration" dimension, we calculated the following parameters to represent peak computer use for each measurement period: (i) the number of days with long duration of computer use; (ii) the number of days with long duration of mouse use; (iii) the number of weeks containing ≥3 days with long duration of computer use; and (iv) the number of weeks containing ≥3 days with long duration of mouse use.

In the "frequency" dimension, we calculated the following parameters for each measurement period: (i) the number of days with high frequency of keyboard use; (ii) the number of days with high frequency of mouse use; (iii) the number of weeks containing ≥3 days with high frequency of keyboard use; and (iv) the number of weeks containing ≥3 days with high frequency of mouse use.

The frequency of keyboard use was calculated as the total number of keystrokes per day divided by the total time of keyboard use. The frequency of mouse use was calculated as the total number of mouse clicks per day divided by the total time of mouse use. Because of the high correlation between the number of mouse clicks and the number of mouse movements, we decided to use mouse clicks as a proxy of total mouse activity in the calculation of mouse use frequency. Keyboard and mouse use frequency were calculated as events per minute. Frequency was assigned a "0" if active keyboard use was <30 minutes or active mouse use was <1 hour. The reason was to avoid that very brief periods of keyboard or mouse use, which in our opinion are too short to cause neck and upper-extremity symptoms, would be classified as peak computer use.

In order to define "peak computer use" in a computer parameter in the duration or frequency dimensions, we applied thresholds to the daily duration or the daily frequency. However, these thresholds were arbitrary, since in the current literature no such thresholds have yet been defined for computer, mouse, and keyboard use. We based our choice of thresholds on the need to to include sufficient participants beyond each threshold for proper analyses. With this in mind, we chose the 75th percentile as a cut-off point. In order to do this, we accumulated all available computer data for every participant and every measurement period. We calculated the 75th percentile for each of the eight computer parameters, and rounded each threshold to the closest whole number to facilitate future research. The thresholds for computer-use duration were set at 4 hours per day, 2.5 hours for mouse-use duration, 20 clicks per minute for peak mouse-use frequency, and 160 strokes per minute for peak keyboard-use frequency. The peak parameters and thresholds are shown in table 2.

Case definition

Data concerning the outcome measure, ie, pain or discomfort in the neck–shoulder (NS) region as well as in the arm–wrist–hand (AWH) region were gathered

Table 2. Computer peak parameters calculated for each exposure measure. [NCT=non-computer threshold (time between two consecutive computer events)]

Dimension	NCT (seconds)	Threshold	Peak parameters
Duration			
Computer use	30	4 hours	# of days ≥ threshold # of weeks ≥3 days above threshold
Mouse use	5	2.5 hours	# of days ≥ threshold # of weeks ≥3 days above threshold
Frequency			
Mouse frequency	5	20/minute and >1 hour	# of days ≥ threshold # of weeks ≥3 days above threshold
Keyboard frequency	2.5	160/minute and >0.5 hours	# of days ≥ threshold # of weeks ≥3 days above threshold

by means of a validated, modified version (19) of the Nordic Questionnaire (20). After every measurement period (ie, every three months), subjects were asked to rate the occurrence of pain or discomfort in the NS and AWH regions in the previous three months on a four-point scale: "no, never"; "yes, sometimes"; "yes, regularly"; "yes, prolonged". Also, eight possible specific causes of these symptoms were noted: sport injuries, accidents, skin diseases, a twist or sprain, a cut or burn, a congenital defect, rheumatic disorders, and a slipped disc. Every measurement period, a case of NS or AWH symptoms was defined as regular or prolonged pain during this period, not caused by any listed specific cause, irrespective of previous periods of pain. Symptoms in the NS and AWH regions were assessed separately. This choice was based on previous work that suggested that the effect of computer use on these two body regions might be different (2).

Assessment of confounders

We selected potential confounders based on previously reported risk factors (16). The variables age, gender, and "symptoms during the year before baseline" were assessed with the baseline questionnaire. Symptoms during the year before baseline were assessed with a question similar to the one assessing the outcome that could be answered with yes or no. The variables "effort–reward ratio" and "computer use during leisure time" were assessed by questionnaire at baseline and 1-year follow-up. The effort–reward ratio was based on the concept of Siegrist's effort–reward imbalance (ERI) model, and effort and reward were measured with the ERI model's recommended scales (21). A validated Dutch version of the questionnaire was used (22), with scores varying from 1 (agree) to 5 (disagree, and I am very distressed). To compute the effort–reward ratio, the effort score served as the numerator and the reversed reward score as the denominator. The latter score was multiplied by a correction factor to adjust for the unequal number of items. Computer use during leisure time was assessed with a question asking how many hours per day the respondent used a computer during leisure time, with seven answer categories, varying from "(almost) never" to "≥8 hours".

Selection of the final study population

Out of the 1951 participants who gave informed consent and completed the first questionnaire, 371 subjects were excluded because they worked ≥2 days per week at another location, and 76 were excluded because they shared a computer account with a colleague. Of 874 participants, data were available on registered computer use for ≥1 measurement period (in total 2518 measurements). Of these participants, questionnaire data were available on NS or AWH symptoms for 774 participants (with 2116 measurements), which were included in the analyses. Registered computer usage was only available for a limited number of participants because the program was not properly installed on their workstations for some measurement periods or their files on their computer usage were not sent to the central computer network due to technical problems. Furthermore, it was assumed the computer-usage registration was unreliable if registrations were available for <70% of the expected workings days in the registration period (adjusted for self-reported holidays and sick leave due to NS or AWH symptoms). Table 1 presents the main characteristics of the participants in the PROMO study and those of final study population. It should be noticed that the latter consisted of subjects with and without symptoms at baseline.

Statistical analysis

Workers with and without symptoms at baseline were followed during follow-up. In this study, data analysis was guided by the notion that NS and AWH symptoms are episodic and recurrent in nature: symptoms are present at a certain time point, symptoms are absent for a certain time period afterwards and then may come back again. The implication for the data analysis was that one subject may have more than one episode of NS or AWH symptoms during the two years of follow-up. Time lags of three months (which equals one measurement period) were defined in order to ensure that exposure preceded the health outcome (see figure 1). With a total of nine measurement periods with nine questionnaires, this means that a maximum of eight combinations of exposure and outcome data with time lags were available. Rate ratios (RR) were obtained from Poisson regression using generalized estimating equations (GEE) (SPSS version 17.0, SPSS Inc, Chicago, IL, USA). GEE takes

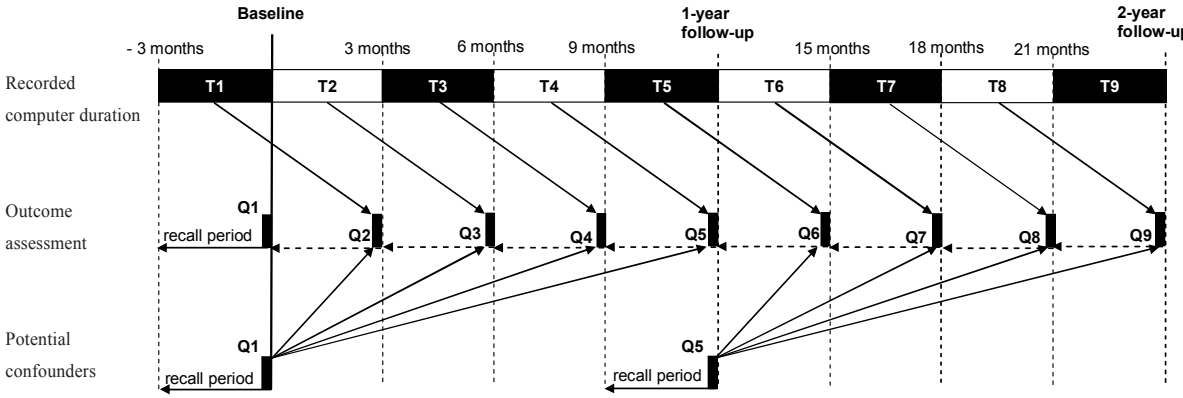

Figure 1. Schematic overview of data collection and statistical analyses. (T1–T9 are the nine time periods; Q1–Q9 are the nine questionnaires).

into account the time varying nature of both the outcome and the exposure. With GEE analysis, the relation between two longitudinally measured variables could be studied using all longitudinal data simultaneously and adjusting for within-person correlations caused by repeated measurement on each subject. Univariate as well as multivariate analyses were performed.

Results

Table 3 shows the characteristics of the analyzed peak parameters during a measurement period of three months, while in table 4 the results of the multivariate analyses are presented. The results of the univariate analyses are not shown, since they do not deviate from the results of the multivariate analyses.

Table 4 shows that no relation was found between peak-day or peak-week parameters and AWH symptoms. Also, none of the parameters in the "duration" dimension had a statistically significant relation with NS symptoms. In the "frequency" dimension, statistically significant relations were found with NS symptoms. A higher occurrence of NS symptoms was related to a lower amount of peak exposure (RR <1) for peak days with a high mouse frequency (≥20 clicks per minute) or with a high keyboard frequency (≥160 strokes per minute) and for peak weeks with a high mouse frequency (≥20 clicks per minute).

Discussion

In this study, we investigated whether the number of days/weeks with a long duration of computer or mouse use or with a high frequency of mouse or keyboard use are risk factors for the occurrence of NS or AWH symptoms. Occurrence could refer to incidence, recurrence, or persistence of symptoms. Neither days/weeks with a long duration of computer or mouse use nor days/weeks with a high frequency of mouse or keyboard use were found to be a risk factor for the occurrence of symptoms.

These results differ from previous studies on the relation between computer use and musculoskeletal symptoms. Reviews concerning this relation concluded a positive relation, although the evidence is limited (1–3). However, our results cannot be compared to the studies included in these reviews since they differ in at least two of the following aspects: (i) exposure to computer use was self-reported, (ii) no peaks in computer use were studied, (iii) the outcome measures were clinically diagnosed symptoms instead of self-reported symptoms, or (iv) the outcome measures were incident symptoms. Unfortunately, we did not find any study using objective exposure measurements and a focus on peak exposure. We did find a very small protective effect of a high keyboard frequency. This result is in line with Andersen et al (4), who found that "speed per 100 keystrokes" was negatively associated with acute shoulder pain. Since the protective effect is so small and the confidence interval close to the null, it would be too speculative to elaborate on this.

The absence in our study of a clear relation between peak exposure regarding long duration or high frequency of computer use on the one hand and musculoskeletal symptoms on the other can be explained by several factors. Firstly, the design of the study only allowed for the analysis of chronic symptoms and not for the analysis of acute symptoms since each questionnaire related to symptoms in the preceding three months, and specific time periods with symptoms could not be distinguished within the three-month period. We chose to define symptoms as regular or prolonged pain. In addition, we used a time lag of three months in order to

Table 3. Characteristics of peak parameters (2116 computer-use measurements from 774 participants). Parameters are quantified as number of days or weeks during one measurement period (three months).

	Range	Median
Peak days		
Peaks in duration		
Computer ≥4 hours (in days)	0–57	15.6
Mouse ≥2.5 hours (in days)	0–56	5.3
Peaks in frequency		
Mouse ≥20/minute (in days)	0–59	4.0
Keyboard ≥160/minute (in days)	0–62	1.1
Peak weeks		
Peaks in duration		
Computer ≥3 days with ≥4 hours (in weeks)	0–13	1.9
Mouse ≥3 days with ≥2.5 hours (in weeks)	0–14	0
Peaks in frequency		
Mouse ≥3 days with ≥20/minute (in weeks)	0–13	0
Keyboard ≥3 days with ≥160/minute (in weeks)	0–13	0

ensure that the exposure always preceded the outcome. This latency period might have been too long to relate some of the reported symptoms to peak computer use. In order to evaluate this, we also performed the analyses without using a time lag, so that exposure and outcome both occurred in the same measurement period of three months. However, the results of these analyses were similar to those of the analyses without a time lag. In both aspects, type of symptoms and latency period, the present study differed from the studies of Chang et al (6) and Andersen et al (4), both of whom found a positive relation. They looked at daily and weekly computer use duration, respectively, in relation to acute musculoskeletal symptoms. Thus, both investigated musculoskeletal symptoms that shortly followed exposure (ie, at the end of that day or week).

Secondly, the thresholds that we used to define peak days and weeks might not have been sensitive enough to discern between workers with high and low exposure. These thresholds were arbitrary, since no literature is available on what daily or weekly level of computer, mouse, or keyboard use might be harmful. We based our thresholds on the 75th percentile of the available data. Having a threshold from the 90th percentile or even higher might have resulted in an exposed group with a more distinct profile. However, a sensitivity analysis using a threshold level close to the 90th percentile taught us that results were similar. The main difference was that effect estimates were no longer statistically significant. A higher threshold would have led to insufficient measurements for the analyses.

The threshold we set for a peak week as having three or more peak days within one calendar week was arbitrary as well. A possible reason for the lack of significant relations with neck and upper-extremity symptoms might be that having only three peak days still leads to sufficient rest periods throughout the work week. A higher number of peak days within one week might lead to different results. Unfortunately, we were unable to investigate this in the current study because of insufficient observations. Also, our definition of a peak week was having three random peak days during one week, since we were not able to identify consecutive peak days within a week, due to technical impracticability. Having a threshold of three consecutive days would induce less rest periods during the week and thus less recovery time, thereby increasing the risk for neck and upper-extremity symptoms. Future research might focus on exploring different patterns of days or weeks with peak exposure.

Thirdly, we did not monitor participants' activities when they were not working with the computer. Information about these periods in between computer use input is important in defining activities that have a sufficiently different muscle activity to increase daily variation, which is thought to prevent musculoskeletal symptoms (14).

Fourthly, because of the episodic nature of NS and AWH symptoms, we selected outcome measures that were a mixture of incident, persistent, and recurrent symptoms. However, the use of incident symptoms might have led to different results.

In addition to the methodological limitations mentioned in the preceding paragraphs, general limitations of the study include the high number of missing values due to technical problems, the relatively low participation rate, and the potentially threatened internal validity by (residual) confounding or effect modification. Residual confounding and effect modification is a threat in all observational studies, as we might miss relevant variables and some variables may be measured imperfectly. The strengths of this study include the long follow-up duration and the assessment of computer use duration with software recordings. The strengths and limitations of the PROMO study have been discussed in detail elsewhere (5).

Finally, this study did not find a positive relation between peak exposure to computer use and NS or AWH symptoms. We mentioned various reasons that might have been responsible for the absence of any effect. They referred to choices we made in the study design and the general limitations of the PROMO study. Obviously another reason why we did not find a positive relation between duration of computer exposure and neck and upper-extremity symptoms may be that the mechanisms leading to these symptoms among office workers are of a different nature than we assumed. The hypothesis that exposure to prolonged computer use leads to neck and upper-extremity symptoms, confirmed by earlier studies using self-reported exposure, could not (or only partly) be confirmed by recent studies using registered computer use. Although

Table 4. Results of the multivariate analysis. Relations are shown between peak day or peak week parameters during a 3-month period and the occurrence of neck–shoulder (NS) or arm–wrist–hand (AWH) symptoms during the following 3-month period (N=2116 measurements, 774 participants).

	NS symptoms [a]		AWH symptoms [a]	
	Rate Ratio	95% CI	Rate Ratio	95% CI
Peak days				
Peaks in duration				
Computer ≥4 hours (in days)	1.00	0.99–1.01	1.01	0.99–1.02
Mouse ≥2.5 hours (in days)	1.00	0.99–1.01	1.01	0.99–1.02
Peaks in frequency				
Mouse ≥20/minute (in days)	0.99	0.98–0.99 [b]	1.00	0.99–1.02
Keyboard ≥160/minute (in days)	0.98	0.97–1.00 [b]	0.99	0.98–1.01
Peak weeks				
Peaks in duration				
Computer ≥3 days with ≥4 hours (in weeks)	0.99	0.95–1.03	1.03	0.99–1.08
Mouse ≥3 days with ≥2.5 hours (in weeks)	0.99	0.95–1.03	1.04	0.99–1.09
Peaks in frequency				
Mouse ≥3 days with ≥20/minute (in weeks)	0.95	0.91–0.99 [b]	1.02	0.97–1.07
Keyboard ≥3 days with ≥160/minute (in weeks)	0.96	0.91–1.01	0.98	0.92–1.05

[a] Analyses are adjusted for age, gender, effort-reward ratio, computer use during leisure time, and symptoms during the year before baseline.
[b] P<0.05.

it was already known that neck and upper-extremity symptoms have a multifactorial origin, the exposure to computer use was always considered as a main risk factor in practice. Perhaps the relation between computer use and neck and upper-extremity symptoms is not as obvious as we assumed.

Future research might explore other potential risk factors, such as psychosocial work characteristics, health beliefs, or cultural differences. Some recent studies show interesting results. For example, a cross-sectional study in Japan and the UK found that large differences exist between the countries in wrist or hand pain and sickness absence due to musculoskeletal pain (23). A cross-sectional study in India and the UK found that cultural factors, such as health beliefs and expectations, may have and important influence on musculoskeletal symptoms (24). Unraveling the mechanism leading to neck and upper-extremity symptoms will remain a real challenge.

Concluding remarks

In this study, we found no indication that periods of high-peak exposure in computer usage were related to NS or AWH symptoms.

Acknowledgements

We thank Stefan IJmker for his contribution to the study setup and the data collection.

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Received for publication: 5 March 2011

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