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Office workers' computer use patterns are associated with workplace stressors

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This field study examined associations between workplace stressors and office workers' computer use patterns. We collected keyboard and mouse activities of 93 office workers (68F, 25M) for approximately two work weeks. Linear regression analyses examined the associations between self-reported effort, reward, overcommitment, and perceived stress and software-recorded computer use duration, number of short and long computer breaks, and pace of input device usage. Daily duration of computer use was, on average, 30 min longer for workers with high compared to low levels of overcommitment and perceived stress. The number of short computer breaks (30 s–5 min long) was approximately 20% lower for those with high compared to low effort and for those with low compared to high reward. These outcomes support the hypothesis that office workers' computer use patterns vary across individuals with different levels of workplace stressors.

1. Introduction

Work-related neck and upper extremity pain constitutes a considerable burden among computer workers with 2-year follow-up prevalence rates of 31, 33, and 21% for neck, shoulder, and forearm/hand symptoms, respectively (Eltayeb et al., 2009). In addition to serious physical consequences for the individuals involved, neck and upper extremity pain results in high costs for society due to productivity loss and sick leave (Hagberg et al., 2007; Van den Heuvel et al., 2007a).

There are numerous observational studies suggesting that neck and upper extremity pain in computer workers can result from workplace stressors. This may be due to an increased physical load observed during exposure to these stressors (Wahlstrom, 2005; NRC/IOM NRCaloM, 2001; Sauter and Swanson, 1996). Workplace stressors include high perceived stress, high work demands (e.g. task difficulty and time pressure), little control at work, low social/work support from colleagues or supervisor, low task variation, high overcommitment, high efforts, and low reward (Bongers et al., 2006; Eltayeb et al., 2009; Huysmans et al., 2012; McLean et al., 2010; Norman et al., 2008; Siegrist et al., 2004). In office workers, effort, reward, overcommitment, and perceived stress were shown to be the workplace stressors most consistently related to neck and upper extremity pain (Bongers et al., 2006; Huysmans et al., 2012; Van den Heuvel et al., 2007b). A higher physical load may include increased muscle activity, more awkward postures, higher keyboard and mouse forces, and high repetition of movements (Eijckelhof et al., 2013a; Ekberg et al., 1995; Nordander et al., 2013;

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Punnett and Wegman, 2004; Wahlstrom, 2005; Sauter and Swanson, 1996; Jensen, 2003).

It is possible that high levels of workplace stressors increase workers' physical load directly through increased general arousal (Bruno Garza et al., 2013; Eijckelhof et al., 2013b). Another option is that with high levels of workplace stress, workers change their individual patterns of exposure (i.e. in terms of duration, frequency, and duty cycle (Potvin, 2012)), as suggested by Bongers et al. (2006). Specifically, three possibilities have been proposed. First, workers with high levels of workplace stressors may spend more time working at their computer (Andersen et al., 2008; Chang et al., 2007; IJmker et al., 2007, 2011). Second, a combination of the number and duration of periods without computer use throughout a workday may be of importance. Workers with high levels of workplace stressors may reduce their computer break periods, increasing the risk of developing acute discomfort or long-term neck and upper extremity pain (Sharan et al., 2011; Henning et al., 1997; Huysmans et al., 2012; McLean et al., 2001; Menendez et al., 2008; Norman et al., 2008; Van den Heuvel et al., 2003). A third possibility is that in addition to computer duration and computer break patterns, workers with high levels of workplace stressors (such as overcommitment) increase the pace of input device usage (Eijckelhof et al., 2013a,b), which could increase the risk of developing neck and upper extremity pain (Nordander et al., 2013).

Previous studies have indicated that individual exposure patterns including computer duration, computer break patterns, and the pace of input device usage may result from increased exposure to stressors. Johnston et al. (2010) demonstrated that workers' responses to supervisor support, decision authority, and skill discretion influenced their exposure as measured through time spent on computer work and mouse use duration. Also, Van den Heuvel et al. (2007b) found that in response to high overcommitment, office workers took fewer computer breaks and had higher self-imposed workload. However, these reports on the relation of job demands and individual exposure patterns, including computer duration and computer break patterns, are based on self-reported computer use data and might differ from directly measured computer duration and break patterns (Barrero et al., 2009; IJmker et al., 2011). When both methods are compared, direct measurements of computer use have been shown to have the highest test–retest reliability (IJmker et al., 2008).

To date, information on the relation between workplace stressors and directly measured patterns of exposure among office workers is scarce and mostly limited to self-reported measures of work patterns or laboratory-based studies. Therefore, in an actual workplace setting using computer interaction monitoring software, this study aimed to examine whether workplace stressors affected directly measured computer work patterns including: the time spent working at the computer, the number and duration of computer breaks, and the pace of input device usage including key strike frequency, the duration of individual key strikes, mouse movement speed and mouse button clicking frequency. We would like to note that the term "computer break", which we use throughout this paper, refers to a period without computer interaction and not necessarily a period of rest.

The aim of our study is to answer the following research question: "Do high levels of workplace stress lead to adverse computer use patterns (i.e. total computer duration, computer break patterns, and the pace of input device usage)?"

We chose to focus on four workplace stressors thought to be risk factors for developing neck and upper extremity pain: 1) effort, 2) reward, 3) overcommitment, and 4) perceived stress (Cohen et al., 1983; Siegrist et al., 2004). The first two stressors represent organizational factors and the latter two represent individual responses to environmental factors.

We hypothesize that high compared to low levels of effort, overcommitment, and perceived stress and low compared to high levels of reward are associated with:

- Longer duration of computer use (more exposure),
- Smaller 8-h frequency of computer breaks (short and long computer breaks);
- Higher pace of work as measured through high key strike frequency, shorter key strike duration, higher mouse movement speed, higher mouse button clicking frequency.

2. Methods

2.1. Experimental design and participants

This study used the data set from the PROOF study (PRedicting Occupational biomechanics in OFfice workers), which had the overall aim to investigate the effects of workplace stressors on biomechanical loading during computer use in office workers in actual field settings. Participants were recruited from 8 departments at the VU University and 1 department at the VU University Medical Center in Amsterdam, The Netherlands (Bruno Garza et al., 2012). One-hundred-twenty workers were recruited for the PROOF study, and to be eligible, their main work tasks had to involve working with the computer (to capture differences which are more likely to result from work-related stress rather than from job content), working at least 20 h per week (to reduce workload differences across the subjects), and being free of musculoskeletal symptoms one week prior to participating in the study (to avoid influence of pain).

All protocols and consent forms were approved by the Harvard School of Public Health Human Subjects Committee, the Medical Ethics Committee of the VU University Medical Center Amsterdam, and the Ethics Committee of the Faculty of Human Movement Sciences of VU University Amsterdam.

2.2. Data collection and data processing

2.2.1. Computer interaction

We installed Computer interaction monitoring (CIM) software, which was a Labview based application, onto the participants' computers. The CIM software ran in the background of the participants' computer for a minimum of one week and automatically recorded the time and duration of each key strike (without the key identified) and each mouse event (cursor movement duration and distance in pixels, scrolling, mouse button activity).

With these event data we calculated periods with and without computer activity, thereby capturing a worker's individual computer use patterns. Computer activity included i) keyboard activities, ii) mouse activities, and iii) idle activities. Keyboard activity was defined as a series of keyboard events (key strikes) that had less than 2 s of inactivity between successive keyboard events. Mouse activity was defined as a series of mouse events (mouse movement, scrolling, or button clicks) that had less than 2 s of inactivity between successive mouse events. Finally, idle activities were defined as any period of keyboard or mouse inactivity that lasted at least 2 s but less than 30 s (Dennerlein and Johnson, 2006; Hwang et al., 2010; Yeh et al., 2009). Idle activities include passive computer-related activities such as viewing the screen. Periods with non-computer activities were defined as any period without computer activity greater than 30 s (Blangsted et al., 2004; Chang et al., 2008) and could represent a rest break or work-related non-computer activity.

2.2.2. Duration of the total workday

Per participant we had between 4 and 10 observations, one for each day, of the time between logging on to the computer and logging off. We averaged these duration data across days into one mean outcome per participant, representing the duration of a workday.

2.2.3. Dependent variables – computer duration

For all observations of each participant, we extracted all periods with computer activity (i.e. keyboard, mouse, and idle activities) and calculated each worker's total duration of computer interaction for each workday. We then averaged these duration data into one mean outcome across days.

2.2.4. Dependent variables – computer break patterns

To calculate the frequency of computer breaks, we extracted all idle activities and each period with non-computer activity across the workday and calculated the number of computer breaks of the following durations:

a. Idle activities ($2 \leq$ duration < 30 s)
b. Short breaks (30 s $\leq$ duration $<$ 5 min)
c. Medium breaks (5 min $\leq$ duration $<$ 15 min)
d. Long breaks (duration $\geq$15 min)

We did this for all observations we had per participant and then averaged these data per workday into one mean outcome across workdays. We then extrapolated the number of computer breaks that were actually measured during a workday to calculate the number of computer breaks during a standardized workday of 8 h, because the number of computer breaks is highly dependent on the total duration of a workday.

2.2.5. Dependent variables – the pace of input device usage

Using the computer activity data we calculated the average values of four different input pace parameters across the actual workday. We defined pace parameters for:

1) Key strike events, including:
   a. Frequency – the number of key strikes per minute;
   b. Duration – the mean duration of the individual key strikes in milliseconds.
2) Mouse events, including:
a. Cursor speed – the speed of the mouse movement, units based on the diagonal length of the participant's screen;
b. Frequency of button clicks – the number of left mouse button clicks per minute.

A participant's data were used in the data analysis if:

a. At least four workdays of data were available (maximally 10 workdays of data were included);
b. Two comparable days across a working week (e.g. two Mondays, or two Tuesdays, and so on) were not included more than twice.

A day was only eligible for inclusion in the analyses if:
The total duration of that day (i.e. time between logging on to the computer and logging off) was at least 1 h.

2.2.6. Independent variables – workplace stress

Via a questionnaire (IJmker et al., 2006) participants reported their levels of effort (5 items) and reward (6 items) using the "effort-reward imbalance at work model (ERI)" (Siegrist, 1996). A participant's level of overcommitment (11 items) was assessed using "the need for control model" (Siegrist et al., 2004), and perceived stress using the "Perceived Stress Scale" (4 items) (Cohen et al., 1983).

The survey also collected information on potential confounders including age, gender, job title (i.e. profession, such as a secretary or other supporting employee, network administrator, etc.), educational level (i.e. highest completed education), work history (i.e. number of years performing a job of which the main tasks are computer related), touch typing skill, and history of musculoskeletal symptoms (i.e. pain or discomfort in neck, shoulders, arms, wrists, hands during the past 12 months, resulting in sick leave, taking pain medication, visiting a doctor, or withdrawal from certain activities).

2.3. Statistical analyses

Participants were categorized into low/medium/high tertiles based on their levels of effort, reward, overcommitment, and perceived stress in order to obtain an equal number of participants in each group. We tested whether mean duration of the total workday (i.e. from logging into the computer to logging out) was comparable between low, medium, and high groups, using ANOVA, to verify that the duration of the total workday was similar across the three groups and hence was not causing other between-group differences.

To test our hypotheses that computer duration, computer break patterns, and the pace of input device usage parameters were different for workers with different levels of i) effort, ii) reward, iii) overcommitment, or iv) perceived stress, we performed linear regression analyses with effort, reward, overcommitment, and perceived stress as the independent (categorical) variables and computer duration, 8-h frequency of computer breaks (i.e. $\geq$2–30 s, $\geq$30 s–5 min, $\geq$5–15 min, and $\geq$15 min), key strikes per minute, keyboard event time in milliseconds, mouse movement speed in NDUs per minute, and number of left mouse button clicks per minute as the dependent variables. Analyses were performed separately for each dependent variable.

To test for possible confounders, we added each potential confounder (i.e. age, gender, job title, educational level, work history, touch typing skill, and history of symptoms) individually to the linear regression analyses. If the effect size (regression coefficient) changed by more than 10%, then the variable was considered as a relevant confounder. Before adding potential confounders to the adjusted models, correlation between these variables was tested. If two or more potential confounders were correlated (i.e. Pearson's $r > 0.60$), only the variable with the strongest modifying effect was maintained in the adjusted analyses. Analyses including all identified confounders are presented as "adjusted models" in the Results section.

The significance level for our main independent variable was set at $p < 0.05$.

3. Results

Of the 120 participants recruited, we successfully collected data for 93 participants (Table 1). Data of 8 recruited participants did not meet the inclusion criteria and one department changed their network erasing 6 participants' CIM data before retrieval. For 13 participants, computer security or use of a non-Windows operating system prevented the use of our CIM software.

3.1. Confounders

The variables age and work history were highly correlated (Pearson's $r = 0.72$). Therefore, only the variable with the strongest confounding effect was used in subsequent models evaluating

Table 1
Participant characteristics.

	Total study population N = 93	Effort (scale: 5–25)			Reward (scale: 11–55)			Overcommitment (scale: 6–24)			Perceived stress (scale: 4–16)		
		Low (mean; range: 6.8; 5–8) N = 30	Medium (mean; range: 10.4; 9–12) N = 31	High (mean; range: 14.4; 13–20) N = 32	Low (mean; range: 38.1; 26–45) N = 29	Medium (mean; range: 50.4; 46–53) N = 37	High (mean; range: 54.5; 54–55) N = 26	Low mean; (range: 8.9; 6–11) N = 26	Medium (mean; range: 13.0; 12–14) N = 38	High (mean; range: 16.6; 15–23) N = 29	Low (mean; range: 3.1; 0–4) N = 36	Medium (mean; range: 5.4; 5–6) N = 30	High (mean; range: 8.0; 7–11) N = 27
Mean age (years)	42.0 (sd: 11.6)	35.9 (sd: 9.9)	43.0 (sd: 12.9)	46.7 (sd: 9.2)	44.3 (sd: 9.3)	42.4 (sd: 12.4)	38.2 (sd: 11.8)	37.5 (sd: 10.1)	43.7 (sd: 11.2)	43.7 (sd: 12.4)	42.2 (sd: 12.9)	40.4 (sd: 11.0)	43.5 (sd: 10.4)
Gender, percentage (number) female workers	73% (68)	77% (23)	71% (22)	72% (23)	72% (21)	70% (26)	77% (20)	65% (17)	71% (27)	83% (24)	58% (21)	83% (25)	81% (22)
Mean work history (number of workers)													
a: <1 year	8	6	2	-	2	1	5	4	3	1	3	4	1
b: 1–2 years	11	6	4	1	1	6	4	4	4	3	3	7	1
c: 2–5 years	22	9	7	6	5	13	4	7	10	5	9	6	7
d: 5–10 years	14	4	3	7	5	5	4	4	5	5	5	2	7
e: >10 years	38	5	15	18	16	12	9	7	16	15	16	11	11
Touch typing skills, percentage (number) of workers	37% (34)	43% (13)	45% (14)	22% (7)	45% (13)	38% (14)	27% (7)	50% (13)	26% (10)	38% (11)	36% (13)	40% (12)	33% (9)
Symptoms the past 12 months, percentage (number) of workers	25% (23)	17% (5)	26% (8)	31% (10)	41% (12)	11% (4)	23% (6)	19% (5)	21% (8)	34% (10)	17% (6)	23% (7)	37% (10)

confounders (i.e. 'work history' in five adjusted models for computer duration and computer break patterns, and 'age' in three adjusted models for the pace of input device usage) (Table 4).

3.2. *Effects of effort, reward, overcommitment, and perceived stress on patterns of computer use*

3.2.1. *Duration of the total workday*

Based on the CIM data of the time between logging on to the computer and logging off, the mean duration of the total workday was 6.5 h (sd = 1.1 h) for the complete study population. There were no statistically significant differences in duration of the total workday between the low, medium and high groups for effort, reward, overcommitment, and perceived stress (Table 2).

3.2.2. *Dependent variables – computer duration*

Workers with high levels of overcommitment on average spent significantly more time interacting with the computer per workday, compared to workers with low levels of overcommitment; this difference was approximately 30 min of computer interaction per day (Table 2). Similarly, workers with high levels of perceived stress on average interacted 30 min more with the computer per workday compared to workers with low levels of perceived stress (Table 2). After controlling for confounding by work history and history of symptoms both these results remained significant (Table 4). We found no differences in duration of computer interaction when the subjects were grouped by effort and reward.

3.2.3. *Dependent variables – computer break patterns*

When subjects were grouped by effort, there were differences in the 8-h frequency idle activities (≥2–30 s) and short (≥30 s–5 min) computer breaks (Table 2). Workers with high or medium compared to low levels of effort, had 17% fewer idle activity episodes (≥2–30 s) across a workday. The number of short computer breaks (≥30 s–5 min) was on average 20% lower in workers with high compared to low levels of effort. In contrast, we found a positive trend for high compared to low effort on the number of long duration computer breaks (≥15 min).

When subjects were grouped by reward, similar effects were seen, revealing that the number of short computer breaks (≥30 s–5 min) was significantly less in the low reward group compared to the high reward group (Table 2). When subjects were grouped by other workplace stressors, no differences were found in the number of idle activity episodes, short, medium, or long computer breaks (i.e. ≥2–30 s, ≥30 s–5 min, ≥5–15 min, or ≥15 min). After controlling for confounding, including: job title, educational level, work history, touch typing skill, and history of symptoms, the differences in short and long duration computer breaks between the effort groups were no longer significant but remained statistically significant between the reward groups (Table 4). The effect of reward (i.e. low reward compared to high reward) on the number of short breaks (≥30 s–5 min) was actually stronger in the adjusted model (Tables 2 and 4).

3.2.4. *Dependent variables – the pace of input device usage*

When testing the effects of effort, reward, overcommitment and perceived stress on pace of input device usage, we found no effects for any of the workplace stressors on any of the pace of input device usage outcomes (i.e. neither key strike frequency, key strike duration, mouse movement speed, nor mouse button clicking frequency) (Table 3). However, after adjusting for age, which was the only indentified relevant confounder for all input device pace parameters, workers with high compared to low levels of effort appeared to have a significantly shorter key strike duration (Table 4). Furthermore, workers with medium levels of reward

Table 2
Results of the effects of effort, reward, overcommitment, and perceived stress on total computer interaction and 8-h frequency of computer breaks (crude models).

		Low		Medium		High		Regression coefficient		*p*-value	
		Mean	SD	Mean	SD	Mean	SD	Low–Medium[a]	Low–High[b]	Low–Medium[a]	Low–High[b]
Measurement time											
Duration of the total workday (min/day)	Effort	390	67	387	58	396	74				
	Reward	389	61	384	75	402	60				
	Overcommitment	406	65	386	75	385	53				
	Perceived stress	395	63	397	74	379	62				
Computer duration											
Total computer interaction (min/day)	Effort	160	52	174	58	175	47	13.19	14.12	0.33	0.29
	Reward	167	53	172	50	168	58	4.47	−0.44	0.74	0.98
	Overcommitment	156	52	167	52	185	52	11.37	28.48	0.39	0.04[c]
	Perceived stress	153	51	175	56	185	45	22.01	31.86	0.08	0.02[c]
8-h Frequency of computer breaks											
Idle activity episodes ≥2–30 s	Effort	852.7	216.5	709.4	238.7	708.4	229.9	−143.27	−144.34	0.02[c]	0.02[c]
	Reward	704.3	239.8	779.5	253.9	784.5	204.5	−4.97	−80.20	0.94	0.21
	Overcommitment	798.5	214.2	733.7	247.5	744.8	242.3	−64.73	53.71	0.29	0.40
	Perceived stress	746.8	197.4	723.6	253.7	801.8	263.6	−23.20	55.05	0.69	0.36
Short breaks ≥30 s–5 min	Effort	51.8	17.9	49.6	19.2	41.9	15.4	−2.28	−9.90	0.61	0.03[c]
	Reward	43.8	14.7	45.8	18.5	53.8	18.9	−7.96	−9.94	0.08	0.04[c]
	Overcommitment	49.7	16.4	44.0	18.1	50.6	18.7	−5.70	0.92	0.21	0.85
	Perceived stress	47.6	18.9	48.2	17.1	47.2	18.0	0.61	−0.43	0.89	0.93
Medium breaks ≥5–15 min	Effort	5.7	2.0	6.3	2.8	5.6	1.9	0.56	−0.10	0.34	0.86
	Reward	5.9	1.8	5.5	2.2	6.3	2.8	−0.84	−0.42	0.16	0.49
	Overcommitment	5.7	2.2	5.8	2.1	6.2	2.6	0.03	0.43	0.95	0.49
	Perceived stress	5.8	2.3	6.0	2.3	5.9	2.3	0.18	0.05	0.75	0.93
Long breaks ≥15 min	Effort	3.2	1.3	3.8	1.4	3.9	1.4	0.56	0.64	0.09	0.05[c]
	Reward	3.8	1.3	3.6	1.4	3.4	1.1	0.20	0.36	0.54	0.31
	Overcommitment	3.4	0.9	3.9	1.4	3.5	1.4	0.51	0.08	0.12	0.81
	Perceived stress	3.6	1.1	3.8	1.5	3.5	1.3	0.25	−0.14	0.43	0.68

[a] For reward, read High–Medium.
[b] For reward, read High–Low.
[c] $p < 0.05$.

moved their computer mouse significantly faster than workers with high levels of reward and workers with medium compared to low levels of overcommitment clicked significantly more times per minute with the mouse (Table 4).

4. Discussion

4.1. Summary of main results

The goal of this study was to examine whether total computer duration, computer break patterns, and the pace of input device usage parameters varied across individuals with different factors of workplace stress. Overall, we observed individuals with different levels of perceived stress and overcommitment having different durations of computer activity and individuals with different levels of effort and reward having different numbers of short breaks. In general these results supported our hypotheses; however, in contrast with the hypothesized relationship, we did observe a trend that those with higher levels of effort had more long breaks.

In terms of how stress is associated with different frequency of breaks, our results did not fully confirm our hypothesis and were not significant when potential cofounders were included in the models. The effects of effort disappeared after controlling for confounding. However, it may be argued that educational level, work history, and touch typing skill, that were indentified as relevant confounders in the association of effort and computer break patterns (Table 3), are on the causal pathway. In that case, the effects of effort we found in the crude analyses might also be important, indicating that workers with high effort took fewer shorter duration computer breaks (i.e. ≥2–30 s and ≥30 s–5 min). Workers with low reward also had fewer shorter duration computer breaks across a workday, which might be explained by the suggestion that they strive for more reward. They might fear that taking frequent computer breaks throughout the workday will negatively affect their work and/or that it will impact their manager's or co-workers perception of their effort, which is in line with findings of McLean et al. (2001). Another possibility is that their type of work or work environment does not allow short inter-collegial (work-related) conversations.

Contrary to our hypothesis, the pace of input device usage (i.e. the frequency component of computer use patterns) varied little across individuals with different levels of stress with no statistically significant differences. We only found that workers with high levels of effort showed a decreased key strike duration as compared to workers with low levels of effort in the analyses adjusted for age. On a group level, key strike duration decreased by 22 ms on average (Table 4). This seems like a small effect, however, compared to the overall key strike duration of the total study population, which was 117 ms (sd = 42), this can be considered quite substantial (roughly 20%). Furthermore, we expected to find increased mouse movement speed, especially for highly overcommitted workers, because in our previous study wrist radial-ulnar velocities and accelerations were found to be higher in this group of workers (Eijckelhof et al., 2013a). However, the data did not support this hypothesis. Possibly the increased wrist velocities and accelerations were the result of faster movements between the keyboard and mouse or faster movements during keyboard use instead of faster mouse movements. A possible explanation for finding a significant difference for only keyboard work pace might be that computer work often includes other cognitively demanding tasks. A common motor strategy to cope with high cognitive demands, while performing fine motor movements, is to decrease movement velocity (Eijckelhof et al., 2013b). On the one hand workers with high levels of workplace stress may tend to work faster, on the other hand they may have increased cognitive demands (e.g. concentration), which in turn tends to decrease a worker's work pace. The combined effect might result in no differences in work pace across the input devices.

Table 3
Results of the effects of effort, reward, overcommitment, and perceived stress on work pace (crude models).

		Low		Medium		High		Regression coefficient		p-value	
		Mean	SD	Mean	SD	Mean	SD	Low–Medium[a]	Low–High[b]	Low–Medium[a]	Low–High[b]
Work pace											
Key strike frequency of computer interaction time (key strikes/min)	Effort	21	5	20	4	20	4	−0.90	−1.43	0.40	0.18
	Reward	19	4	21	5	21	3	0.60	−1.52	0.57	0.17
	Overcommitment	21	4	20	4	20	5	−0.15	−0.37	0.88	0.75
	Perceived stress	20	3	21	5	20	4	0.73	−0.11	0.48	0.92
Key strike duration (ms)	Effort	117	33	127	58	106	27	10.12	−10.70	0.34	0.31
	Reward	117	29	121	59	111	21	9.66	5.84	0.38	0.61
	Overcommitment	112	33	111	25	129	61	−1.26	17.01	0.91	0.13
	Perceived stress	122	56	111	23	115	36	−10.41	−6.39	0.32	0.55
Mouse movement speed (NDU/min)	Effort	16	3	16	4	15	4	−0.09	−0.75	0.92	0.43
	Reward	15	3	17	4	15	4	1.59	−0.25	0.09	0.80
	Overcommitment	16	3	15	4	16	4	−0.50	−0.24	0.61	0.81
	Perceived stress	16	4	16	4	15	3	0.06	−1.04	0.95	0.28
Left mouse button clicking frequency of computer interaction time (clicks/min)	Effort	4.3	2.5	3.7	2.0	3.8	1.7	−0.62	−0.50	0.24	0.35
	Reward	4.1	2.1	3.7	2.0	3.9	2.3	−0.15	0.26	0.78	0.64
	Overcommitment	3.5	1.8	4.2	2.2	4.0	2.1	0.72	0.55	0.17	0.33
	Perceived stress	3.8	2.1	3.7	2.0	4.3	2.1	−0.08	0.44	0.87	0.41

[a] For reward, read High–Medium.
[b] For reward, read High–Low.

It was striking that workers with high levels of individually oriented workplace stressors (i.e. overcommitment and perceived stress) tended to extend their computer duration across a workday, while these stressors had no effect on computer break patterns. On the other hand, organizationally oriented workplace stressors (i.e. effort and reward), which a worker experienced as burdensome, affected break patterns. The distribution of computer breaks throughout a workday mainly differed in a reduced number of short computer breaks and, in case of high effort, slightly increased 8-h frequency of computer breaks longer than 15 min. Possibly, workers with high levels of organizationally oriented stressors prefer longer uninterrupted periods of computer work.

Our finding that patterns of computer use differed across levels of work stress supports the idea that relations between stress and work-related neck and upper extremity pain could be accounted for by differences in physical load. This pathway is supported by other research that demonstrates that when exposure to physical factors is taken into consideration the relationship between stressors and health outcomes becomes weaker (Bongers et al., 2002; Van den Heuvel et al., 2005). Our finding that computer duration increases with stress supports this idea because duration of computer use is one of the most reported physical risk factors for neck and upper extremity pain in the literature, albeit mostly based on self-report (Gerr et al., 2004; IJmker et al., 2007, 2011; Village et al., 2005).

4.2. *Strengths and limitations*

An important strength of this study is that we collected our data in a natural work situation. To date, most of the frequency and duration of computer input device usage has been obtained in laboratory settings, challenging external validity. Second, most published data on computer duration and computer break patterns is self-reported and might have low validity (IJmker et al., 2008). In this study, we captured workers' computer duration, computer break patterns, and pace of input device usage with the use of computer interaction monitoring software, which yields detailed data. Also, we examined computer break patterns by the 8-h frequency of computer breaks in combination with computer break duration.

Table 4
Results adjusted for confounding (age, work history, education level, job type, touch typing skill, and/or history of symptoms).

		Confounder(s) corrected for	Regression coefficient		p-value	
			Low–Medium[a]	Low–High[b]	Low–Medium[a]	Low–High[b]
Computer duration						
Total computer interaction (min/day)	Overcommitment	Work history	13.59	32.19	0.31	0.03[c]
	Perceived stress	History of symptoms	19.54	25.12	0.11	0.05[c]
8-h Frequency of computer breaks						
≥2–30 s	Effort	Educational level, work history	−74.59	−77.29	0.22	0.22
≥30 s–5 min	Effort	Work history, touch typing skill, history of symptoms	1.26	−5.19	0.78	0.29
	Reward	Job title, work history, touch typing skill, history of symptoms	−7.91	−11.88	0.06	0.01[c]
≥15 min	Effort	Educational level, work history	0.17	0.16	0.60	0.64
Work pace						
Key strike duration (ms)	Effort	Age	2.59	−22.12	0.81	0.05
Mouse movement speed (NDU/min)	Reward	Age	1.96	0.29	0.04[c]	0.77
Left mouse button clicking frequency of computer interaction time (clicks/min)	Overcommitment	Age	1.12	0.94	0.03[c]	0.08

[a] For reward, read High–Medium.
[b] For reward, read High–Low.
[c] $p < 0.05$.

A limitation of the present study might be that the number of days with data included in the analysis differed largely between participants: mean 6.6 days, range 4–10 days. However, we expect that this has not influenced the results of this study, since only for few participants in our data set (15 participants) the extremes of 4 or 10 days were included. Another limitation is that we have extrapolated the data pertaining to breaks, although there is no information available on the accuracy of such extrapolation. Furthermore, even though we examined the 8-h frequency of computer breaks that workers took across a workday in combination with break duration, we still do not know what the activities of the workers were during these computer breaks. Absence of keyboard, mouse, or idle activity cannot simply be viewed as a break from work as there may be significant cognitive load during these periods which could in themselves have an impact on the work-related stress the workers perceive.

5. Conclusion

In conclusion, the hypothesis that adverse workplace stressors increase the risk for developing neck and upper extremity pain through individual computer use patterns (i.e. computer duration, computer break patterns, and the pace of input device usage) is partly supported by the data. It appeared that workers with high levels of individually oriented stressors (i.e. high overcommitment and high perceived stress) extend their computer duration across a workday, while the duration of the workday itself is not extended. Workers with high levels of organizationally oriented stressors (i.e. high effort and low reward) tended to have fewer short (≥2–30 s and ≥30 s–5 min) computer breaks across a workday. The pace of input device usage was weakly affected by the workplace stressors, with the strongest positive association for high levels of effort and key strike duration.

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References

Andersen, J.H., Harhoff, M., Grimstrup, S., Vilstrup, I., Lassen, C.F., Brandt, L.P.A., Kryger, A.I., Overgaard, E., Hansen, K.D., Mikkelsen, S., 2008. Computer mouse use predicts acute pain but not prolonged or chronic pain in the neck and shoulder. Occup. Environ. Med. 65, 126–131.

Barrero, L.H., Katz, J.N., Perry, M.J., Krishnan, R., Ware, J.H., Dennerlein, J.T., 2009. Work pattern causes bias in self-reported activity duration: a randomised study of mechanisms and implications for exposure assessment and epidemiology. Occup. Environ. Med. 66, 38–44.

Blangsted, A.K., Hansen, K., Jensen, C., 2004. Validation of a commercial software package for quantification of computer use. Int. J. Ind. Ergon. 34, 237–241.

Bongers, P.M., Kremer, A.M., ter Laak, J., 2002. Are psychosocial factors, risk factors for symptoms and signs of the shoulder, elbow, or hand/wrist? A review of the epidemiological literature. Am. J. Ind. Med. 41, 315–342.

Bongers, P.M., IJmker, S., Van den Heuvel, S., Blatter, B.M., 2006. Epidemiology of work related neck and upper limb problems: psychosocial and personal risk factors (part I) and effective interventions from a bio behavioural perspective (part II). J. Occup. Rehabil. 16, 279–302.

Bruno Garza, J.L., Eijckelhof, B.H., Johnson, P.W., Raina, S.M., Rynell, P.W., Huysmans, M.A., van Dieen, J.H., van der Beek, A.J., Blatter, B.M., Dennerlein, J.T., 2012. Observed differences in upper extremity forces, muscle efforts, postures, velocities and accelerations across computer activities in a field study of office workers. Ergonomics 55, 670–681.

Bruno Garza, J.L., Eijckelhof, B.H., Huysmans, M.A., Catalano, P., Katz, J., Johnson, P.W., van Dieen, J.H., van der Beek, A.J., Dennerlein, J.T., 2013. The effect of over-commitment and reward on trapezius muscle activity and shoulder, head, neck, and torso postures during computer use in the field. Am. J. Ind. Med. 56, 1190–1200.

Chang, C.H.J., Amick, B.C., Menendez, C.C., Katz, J.N., Johnson, P.W., Robertson, M., Dennerlein, J.T., 2007. Daily computer usage correlated with undergraduate students' musculoskeletal symptoms. Am. J. Ind. Med. 50, 481–488.

Chang, C.H., Johnson, P.W., Dennerlein, J.T., 2008. A wide range of activity duration cut-offs provided unbiased estimates of exposure to computer use. J. Occup. Environ. Hyg. 5, 790–796.

Cohen, S., Kamarck, T., Mermelstein, R., 1983. A global measure of perceived stress. J. Health Soc. Behav. 24, 385–396.

Dennerlein, J.T., Johnson, P.W., 2006. Different computer tasks affect the exposure of the upper extremity to biomechanical risk factors. Ergonomics 49, 45–61.

Eijckelhof, B.H., Bruno Garza, J.L., Huysmans, M.A., Blatter, B.M., Johnson, P.W., van Dieen, J.H., van der Beek, A.J., Dennerlein, J.T., 2013a. The effect of over-commitment and reward on muscle activity, posture, and forces in the arm-wrist-hand region – a field study among computer workers. Scand. J. Work Environ. Health 39, 379–389.

Eijckelhof, B.H., Huysmans, M.A., Bruno Garza, J.L., Blatter, B.M., van Dieën, J.H., Dennerlein, J.T., van der Beek, A.J., 2013b. The effects of workplace stressors on muscle activity in the neck-shoulder and forearm muscles during computer work: a systematic review and meta-analysis. Eur. J. Appl. Physiol. 113, 2897–2912.

Ekberg, K., Karlsson, M., Axelson, O., Malm, P., 1995. Cross-sectional study of risk factors for symptoms in the neck and shoulder area. Ergonomics 38, 971–980.

Eltayeb, S., Staal, J.B., Hassan, A., de Bie, R.A., 2009. Work related risk factors for neck, shoulder and arms complaints: a cohort study among Dutch computer office workers. J. Occup. Rehabil. 19, 315–322.

Gerr, F., Marcus, M., Monteilh, C., 2004. Epidemiology of musculoskeletal disorders among computer users: lesson learned from the role of posture and keyboard use. J. Electromyogr. Kinesiol. 14, 25–31.

Hagberg, M., Vilhemsson, R., Tornqvist, E.W., Toomingas, A., 2007. Incidence of self-reported reduced productivity owing to musculoskeletal symptoms: association with workplace and individual factors among computer users. Ergonomics 50, 1820–1834.

Henning, R.A., Jacques, P., Kissel, G.V., Sullivan, A.B., teras-Webb, S.M., 1997. Frequent short rest breaks from computer work: effects on productivity and well-being at two field sites. Ergonomics 40, 78–91.

Huysmans, M.A., IJmker, S., Blatter, B.M., Knol, D.L., van Mechelen, W., Bongers, P.M., van der Beek, A.J., 2012. The relative contribution of work exposure, leisure time exposure, and individual characteristics in the onset of arm-wrist-hand and neck-shoulder symptoms among office workers. Int. Arch. Occup. Environ. Health 85, 651–666.

Hwang, Y.H., Chen, Y.T., Yeh, J.Y., Liang, H.W., 2010. Effects of passive computer use time and non-computer work time on the performance of electronic activity monitoring. Ergonomics 53, 1254–1262.

IJmker, S., Blatter, B.M., van der Beek, A.J., van Mechelen, W., Bongers, P.M., 2006. Prospective research on musculoskeletal disorders in office workers (PROMO): study protocol. BMC Musculoskelet. Disord. 7, 55.

IJmker, S., Huysmans, M.A., Blatter, B.M., van der Beek, A.J., van Mechelen, W., Bongers, P.M., 2007. Should office workers spend fewer hours at their computer? A systematic review of the literature. Occup. Environ. Med. 64, 211–222.

IJmker, S., Leijssen, J.N.M., Blatter, B.M., van der Beek, A.J., van Mechelen, W., Bongers, P.M., 2008. Test-retest reliability and validity of self-reported duration of computer use at work. Scand. J. Work Environ. Health 34, 113–119.

IJmker, S., Huysmans, M.A., van der Beek, A.J., Knol, D.L., van Mechelen, W., Bongers, P.M., Blatter, B.M., 2011. Software-recorded and self-reported duration of computer use in relation to the onset of severe arm-wrist-hand pain and neck-shoulder pain. Occup. Environ. Med. 68, 502–509.

Jensen, C., 2003. Development of neck and hand-wrist symptoms in relation to duration of computer use at work. Scand. J. Work Environ. Health 29, 197–205.

Johnston, V., Jull, G., Souvlis, T., Jimmieson, N.L., 2010. Interactive effects from self-reported physical and psychosocial factors in the workplace on neck pain and disability in female office workers. Ergonomics 53, 502–513.

McLean, L., Tingley, M., Scott, R.N., Rickards, J., 2001. Computer terminal work and the benefit of micro breaks. Appl. Ergon. 32, 225–237.

McLean, S.M., May, S., Klaber-Moffett, J., Sharp, D.M., Gardiner, E., 2010. Risk factors for the onset of non-specific neck pain: a systematic review. J. Epidemiol. Community Health 64, 565–572.

Menendez, C.C., Amick, B.C., Chang, C.H.J., Dennerlein, J.T., Harrist, R.B., Jenkins, M., Robertson, M., Katz, J.N., 2008. Computer use patterns associated with upper extremity musculoskeletal symptoms. J. Occup. Rehabil. 18, 166–174.

Nordander, C., Ohlsson, K., Akesson, I., Arvidsson, I., Balogh, I., Hansson, G.A., Stromberg, U., Rittner, R., Skerfving, S., 2013. Exposure-response relationships in work-related musculoskeletal disorders in elbows and hands – a synthesis of group-level data on exposure and response obtained using uniform methods of data collection. Appl. Ergon. 44, 241–253.

Norman, K., Floderus, B., Hagman, M., Toomingas, A., Tornqvist, E.W., 2008. Musculoskeletal symptoms in relation to work exposures at call centre companies in Sweden. Work 30, 201–214.

NRC/IOM NRCaloM, 2001. Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities. National Academy Press, Washington, DC.

Potvin, J.R., 2012. Predicting maximum acceptable efforts for repetitive tasks: an equation based on duty cycle. Hum. Factors 54, 175–188.

Punnett, L., Wegman, D.H., 2004. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. J. Electromyogr. Kinesiol. 14, 13–23.

Sauter, S.L., Swanson, N.G., 1996. An ecological model of musculoskeletal disorders in office work. In: Moon, S.D., Sauter, S.L. (Eds.), Beyond Biomechanics:

Psychosocial Aspects of Musculoskeletal Disorders in Office Work. Taylor and Francis Inc., Bristol, pp. 3–21.
Sharan, D., Parijat, P., Sasidharan, A.P., Ranganathan, R., Mohandoss, M., Jose, J., 2011. Workstyle risk factors for work related musculoskeletal symptoms among computer professionals in India. J. Occup. Rehabil. 21, 520–525.
Siegrist, J., 1996. Adverse health effects of high-effort/low-reward conditions. J. Occup. Health Psychol. 1, 27–41.
Siegrist, J., Starke, D., Chandola, T., Godin, I., Marmot, M., Niedhammer, I., Peter, R., 2004. The measurement of effort-reward imbalance at work: European comparisons. Soc. Sci. Med. 58, 1483–1499.
Van den Heuvel, S.G., IJmker, S., Blatter, B.M., de Korte, E.M., 2007a. Loss of productivity due to neck/shoulder symptoms and hand/arm symptoms: results from the PROMO-study. J. Occup. Rehabil. 17, 370–382.
Van den Heuvel, S.G., van der Beek, A.J., Blatter, B.M., Bongers, P.M., 2007b. Workstyle and overcommitment in relation to neck and upper limb symptoms. Int. J. Behav. Med. 14, 12–20.
Van den Heuvel, S.G., de Looze, M.P., Hildebrandt, V.H., The, K.H., 2003. Effects of software programs stimulating regular breaks and exercises on work-related neck and upper-limb disorders. Scand. J. Work Environ. Health 29, 106–116.
Van den Heuvel, S.G., van der Beek, A.J., Blatter, B.M., Hoogendoorn, W.E., Bongers, P.M., 2005. Psychosocial work characteristics in relation to neck and upper limb symptoms. Pain 114, 47–53.
Village, J., Teschke, K., Rempel, D., 2005. Musculoskeletal disorders of the upper extremity associated with computer work: a systematic review. Occup. Ergon. 5, 205–218.
Wahlstrom, J., 2005. Ergonomics, musculoskeletal disorders and computer work. Occup. Med. (Lond.) 55, 168–176.
Yeh, J.Y., Liang, H.W., Hwang, Y.H., 2009. The effect of idle time thresholds on computer use time estimations by electronic monitoring. Ergonomics 52, 872–881.