Int Arch Occup Environ Health (2012) 85:493–503
DOI 10.1007/s00420-011-0696-6

ORIGINAL ARTICLE

Multivariate, longitudinal analysis of the impact of changes in office work environments on surface electromyography measures

D. C. Cole · C. Chen · S. Hogg-Johnson · D. Van Eerd · A. Mazumder · R. P. Wells · Worksite Upper Extremity Research Group

Received: 12 April 2011 / Accepted: 19 August 2011 / Published online: 1 September 2011
© Springer-Verlag 2011

Abstract

Purpose To detect impacts of changes in work environment and worker-equipment interface variables upon surface electromyography (EMG) measures using multivariate, longitudinal analysis.

Methods For 33 office workers, yearly measurements (1999–2001) were taken during normal work. Independent variables were related to work environment (expert-observed equipment dimensions, work organization on questionnaire) and interface (expert-observed postures, self-reported workstation-equipment relative fit i.e. inside or outside guidelines-informed location, and 30 min video-based task analysis). Internal mechanical exposure (EMG) was recorded bilaterally from extensor carpi radialis brevis (ECRB) and upper trapezius sites, each side, also for 30 min. Dependent variables were amplitude probability distribution functions (APDF 50 and 90%) and gaptime for entire record EMG (over all tasks) and task-specific EMG (for four separate tasks). Multivariate mixed models used independent variables to predict EMG measures (4 muscle sites × (1 entire record + 4 task specific) = 20 models total).

Results Among EMG measures, 9/16 means and 2/16 variances were significantly different across years ($p < 0.1$). Environment and interface variables explained part of the variation in EMG measures in 13/20 models. The most consistent predictors included: (1) increased monitor distance predicted reduced APDFs and increased gaptimes; (2) wrist extension <20° predicted decreases in left ECRB APDFs; (3) keyboard location within guidelines predicted improvements in all right ECRB EMG measures during keyboarding; and (4) longer task duration predicted higher APDFs and lower gaptimes.

Conclusion Longitudinal analysis with multivariate models can detect the impacts of changes in environment and interface exposures on EMG measures among office workers.

Keywords Computer workstations · VDTs · Electromyography · Longitudinal studies · Musculoskeletal diseases

D. C. Cole · C. Chen · S. Hogg-Johnson · D. Van Eerd · R. P. Wells
Institute for Work and Health, Toronto, ON, Canada

D. C. Cole (✉) · S. Hogg-Johnson
Dalla Lana School of Public Health, University of Toronto, 6th Floor Health Sciences Building, 155 College Street, Toronto, ON M5T 3M7, Canada
e-mail: donald.cole@utoronto.ca

D. Van Eerd · R. P. Wells
Department of Kinesiology, University of Waterloo, Waterloo, ON, Canada

A. Mazumder
Department of Statistics, University of Oxford, Oxford, UK

Introduction

Office workers engaged in intensive computer work have been shown to be at increased risk of musculoskeletal disorders (MSDs) associated with inadequate workplace design and inappropriate work organization (Sandsjo and Kadefors 2001). In particular, incidence of neck and upper limb symptoms has been predicted by work environment characteristics (van den Heuvel et al. 2006; Tornqvist et al. 2009). Cognizant of these risks, workplaces may respond with a variety of equipment, software, training, work organization and treatment initiatives as part of both ongoing business innovations or specifically to deal with MSDs (Brewer et al. 2006). Understanding how changes in work environments can modify exposure and prevent musculoskeletal disorders (Burdoff 2010) requires accurate measures of both changes and worker exposures in workplaces undergoing change (Cole et al. 2002). Given variability in biomechanical exposure (Mathiassen 2006), measures of worker-equipment interfaces and internal exposure relevant to physical workload and MSDs are required (Hansson et al. 2009, 2010).

Surface electromyography (EMG) is one such commonly used internal exposure assessment method. It has been used to assess risks for pain in short term studies entirely in the laboratory (Østensvik et al. 2009) or using a laboratory to predict pain and other outcomes prospectively among workers (Madeleine et al. 2003; Steingrímsdóttir et al. 2005). In workplace-based observational studies, EMG has been used with questionnaires (Holte and Westgaard 2002), with workstation assessments/anthropometry (Hansson et al. 2001; Marcus et al. 2002) and with video recordings which synchronize task observations with postural and physiological measurements (Karlqvist et al. 1998). Some authors have used multiple types of measures to focus on particular equipment (e.g. mouse) and/or specific activities (e.g. computer-assisted design) (Jensen et al. 1998). Other researchers have applied combinations of methods to assess the effects of specific differences in exposure conditions: questionnaire and EMG for different pause types (Sundelin and Hagberg 1989); observation and EMG for lowered and tilted work tables permitting alternative postures (Westgaard and Aarås 1985); and EMG training with special myofeedback vests of those experiencing neck and upper limb discomfort (Huis in‘t Veld et al. 2008). Very few have used repeat EMG measures to assess impacts of directly observed exposure changes using longitudinal study designs (Aarås et al. 1998). EMG measures on workers in the field demonstrate substantial variation (Mathiassen 2006). Some researchers have used mixed model analyses across exposure measures to assess the contribution of multiple individual and task factors to explain between-worker variation in muscle activity (Bruno et al. 2010). In longitudinal analysis, the challenge is to detect ‘change amidst the random variation within workers over time, recognizing the diversity of exposure profiles among workers.

In collaborative research with a large newspaper implementing an ergonomics program (Cole et al. 2006), we conducted an intensive exposure assessment sub-study of volunteer office workers using VDTs. In keeping with a framework of linkages between work environments, employee-workstation interfaces, job tasks, and internal exposure indicators (Wells et al. 2004), we collected multiple measures of exposure simultaneously. We have previously reported on our cross-sectional analyses of task measures (Van Eerd et al. 2009) and associations across exposure measures (Van Eerd et al. submitted). As well, we documented changes in relevant equipment, workstation, posture, relative fit and task indicators across 3 years (details in a companion paper, Cole et al. 2010).

In this paper, our research question was: Are yearly EMG measures based on four different muscle-side sites, during different tasks (dependent variables) affected by substantive changes in non-EMG work environment exposure variables (independent variables) across years (longitudinally). Multivariate models were constructed for each muscle-site to simultaneously predict three EMG measures (as dependent variables), parceling out the non-random variation across years to highlight variation explained by change in non-EMG work environment exposure variables (independent variables).

Methods

Design

A repeated measures design was used to examine exposure changes among office workers.

Setting

Offices of a large, metropolitan North American newspaper from 1999 to 2001.

Population

Among office workers participating in an exposure assessment study (Van Eerd et al. submitted), 33 had sufficient non-EMG and EMG data available. However, due to scheduling difficulties every worker could not provide EMG data every year: 26 provided EMG data in 1999; 33, in 2000; and 29 in 2001. They worked in advertising, circulation and finance departments doing a wide variety of clerical, administration, sales, customer accounts and call centre jobs, all involving use of VDT-computers during much of the work day (Van Eerd et al. 2009). All participants provided written informed consent in keeping with approval by the Research Ethics Boards of McMaster University and the University of Waterloo. Mean age of the group was 41.6 years (SD = 10.1), and 72.7% were female. They had a mean height of 167.5 cm (SD = 10.2) and a mean weight of 74.2 kg (SD = 17.1). All used a mouse with their right hand.

Data collection

Non-EMG exposure independent variables

Equipment dimensions and postures Detailed information on measurements is provided elsewhere (Cole et al. 2010; Van Eerd et al. submitted). Trained observers noted *equipment* available for each employee. Measurements of workstation setup were taken at the worker's usual workstation with the worker present. *Dimension*s were measured using a tape measure. The orientation of workstation equipment was determined relative to the J key (center of the keyboard) using a calibrated "bubble" level as a reference when needed. Trained observers assessed bilateral upper-extremity *postural* measures (shoulder, elbow and wrist angles) while workers performed their usual keyboarding tasks in their usual keying position. Hand-held goniometers were used, located on standard anatomical landmarks and body segments (Gerr et al. 2002). Head rotation, viewed from above the worker, was measured as the angle between a line perpendicular to the centre of the monitor and a line from the worker's nose forward. Among the 33 participating workers, 25 had their equipment dimensions and postures measured in 1999, 32 in 2000, and 29 in 2001 (Table 1).

Relative fit For *relative fit*, workers indicated whether the placements of the keyboard, mouse and monitor at their usual workstation, were inside or outside boxes on a diagram (Polanyi et al. 1997). For the phone, workers noted whether they used a hands-free phone, a regular hand-held phone, a cell phone or a phone with shoulder rest (Cole et al. 2006). Among the 33 participating workers, 32 had the relative fit position of their keyboard and phone measured in 1999, 33 in 2000, and 30 in 2001. Among these workers, 24 had the relative fit position of their mouse measured in 1999, 31 in 2000, and 29 in 2001.

Work organization One *work organization* variable which showed change across years (Cole et al. 2010) was included—coordination of work with others, which we previously had found was associated with meeting deadlines (Beech-Hawley et al. 2004). Among the 33 participating workers, 32 provided responses on this work organization variable in 1999, 33 in 2000, and 30 in 2001.

Tasks Direct, real time measures of *tasks* performed by workers were collected to improve accuracy of estimates of time spent performing each task (Engström and Medbo 1997; Homan and Armstrong 2003). As the objective was to determine the change in workstation related task exposures over years rather than to estimate the participants' total mechanical exposure, a continuous 2 h of synchronized video and EMG activity were recorded (see below) when the participant was expected to be near their workstation, i.e. not in meetings, off site etc. From this recording, a 30 min segment when the participant was mainly at their workstation was chosen for analysis. The EMG activity was then segmented by task. The video camera was focused on the worker and included the keyboard, mouse, monitor and as much desk space as possible. A 30 min video recording segment was coded by a trained analyst (Observer Pro 4.0, Noldus Information Technology, Netherlands). Task variables created included percent (%) time in each task and the number of tasks extrapolated to a shift (Van Eerd et al. 2009). Among the 33 participating workers, 25 had task data for 1999, 32 for 2000, and 27 for 2001.

EMG measures (dependent variables)

In keeping with other synchronized approaches (Forsman et al. 2002), a portable EMG signal analysis system (ME300P8, Mega Electronics Ltd, Finland, CMRR 110 dB, 15–500 Hz) was used to record the workers' muscle activity over 2 h on two separate days while workers performed their usual office tasks at their workstation. Standardized silver/silver-chloride disposable electrodes (Mediocost Blue Sensor N-00-S) were placed 2 cm apart after standard skin preparation. Root mean square (RMS) EMG signals were recorded at 10 Hz (detected at a 100 ms duration window) from the extensor carpi radialis brevi (ECRB) site and trapezius site bilaterally. For the ECRB site, the surface electrodes were placed one third of the distance from the lateral epicondyle to the radial styloid. For the trapezius site, the surface electrodes were placed midway between C7 and the acromion. The EMG measures were calibrated to maximum voluntary contractions (MVC): for the ECRB, by workers performing a maximal grasp simultaneously while extending their wrist; and for the trapezius, by workers pulling maximally against straps that were fixed to the floor and looped over their elbows while they stood with their arms straight and both shoulders abducted 90°.

A VHS video camera (no audio), with a wide angle lens, captured the workers performing their usual tasks at their workstation, their computer, and office equipment as well as much of their desk space. EMG collection started in view of the video camera recording to permit synchronization during a 30 min period. Synchronization between video and EMG was accomplished by recording distinct periodic electronic signals or "marks" at the start, change, and end of tasks, using a switch on the EMG recording system, capturing the deployment of the switch on video (Moore et al. 2003), and producing a time stamped text file. Video footage was not available for all tasks on all workers, and use of a headset made interpretation of phone use

Table 1 Relevant changes in equipment, work organization, postures, relative fit and tasks, across years

Domain	Variables	1999	2000	2001
Equipment and dimensions	Keyboard support present #	8/25 (36%)	25/32 (86%)	19/29 (73%)
	Keyboard-height to seat [cm, mean (SD)]	18.2 (3.6))	19.0 (3.1)	22.1 (4.0)
	Monitor-table edge to center screen [cm, mean (SD)]	27.4 (12.7)	37.1 (10.8)	37.4 (11.4)
	Monitor-height to seat [cm, mean (SD)]	63.6 (10.0)	69.9 (10.8)	72.0 (5.2)
	Mouse-J key to center pad [cm, mean (SD)]	34.5 (20.1)	40.5 (4.7)	40.7 (3.2)
	Mouse-table edge to center pad [cm, mean (SD)]	15.7 (20.2)	13.6 (6.4)	14.3 (4.6)
Postures #	Left wrist/ulnar deviation angle (>10°)	17/25 (74%)	8/32 (28%)	13/29 (50%)
	Left wrist extension angle (>20°)	2/25 (8%)	13/32 (45%)	4/29 (15%)
	Head rotation angle (degrees, mean (SD))	48.2 (24.5)	4.3 (7.7)	7.7 (9.0)
Relative fit #	Keyboard within box	22/32 (69%)	22/33 (67%)	26/30 (87%)
	Mouse within box	13/24 (54%)	17/31 (55%)	22/29 (76%)
	Phone more flexible options, for e.g. hands free phone	18/32 (44%)	13/33 (39%)	9/30 (30%)
Work organization	Working together with other people, coordinating work with others (1 = strongly disagree, 10 = strongly agree) (mean, SD)	6.56 (2.24)	7.15 (2.24)	6.90 (2.17)
Tasks	# of tasks in a shift (mean, SD)	5.7 (1.1)	6.0 (1.2)	6.1 (1.4)
	% duration-deskwork (mean, SD)	45 (27)	41 (23)	28 (19)
	% duration-keyboarding (mean, SD)	21 (22)	25 (19)	29 (22)

Measurement details are in Van Eerd et al. (submitted) and Cole et al. (2010). Significance of changes are also reported in the latter

N's vary according to measures available

difficult on video without audio. Hence, the number of workers and time spent on tasks varied for the three office tasks (keying $n = 30$, mousing $n = 24$, and phone use $n = 17$).

Task specific EMG data were extracted from the synchronized video and EMG recordings for each worker (Moore et al. 2003; Van Eerd et al. submitted). The task specific EMG data were then concatenated across all portions of the task specific EMG (e.g. mousing). The remainder of the EMG signal was then concatenated as non-task specific EMG sample (i.e. not using a mouse). The entire 30 min set of data we labeled as "entire record" to distinguish from extracted task-specific data. The amplitude probability distribution function (APDF) at the 10th (static), 50th (dynamic) and 90th (peak) percentile (Jonsson et al. 1988) and gaptime (<0.5% MVC value for at least 200 ms) in s/min (Veiersted et al. 1993) were calculated for both the entire record and each of the task-specific EMG signals using custom software.

Statistical analysis

All analyses used the SAS statistical package V9.1. (2002–2003). For *Differences in EMG across years* on the entire record data, Levene's test (1960) was used to assess equality of variance across years, as we were interested in changes in EMG that might be associated with greater task flexibility. Extreme values in left ECRB APDF 50 and APDF 90 measures were observed for one participant so s/he was excluded from the analysis of entire record EMG measures. The distribution of APDF 10 values deviated substantially from normal. Further, across 60 correlations (entire record and task specific $(1 + 4 = 5) \times$ four muscle-side sites $\times$ 3 years), values for APDF 10 and gaptime were negatively correlated: $r = -0.25$ to -0.62, as per the work of Hansson et al. (2009). Because of this moderate magnitude of correlation, APDF 10 was dropped and only gaptime was retained in further analyses.

For *Explaining variation in EMG across years with non-EMG variables* multivariate mixed models of entire record and task-specific data were built for each muscle-site to simultaneously predict values for the three EMG measures (APDF 50, APDF 90, gaptime) across years (Gao et al. 2006), in keeping with others' suggestions (Hansson et al. 2009). Two covariance structures were implemented in the models to simultaneously account for: (1) the errors correlated for the same EMG measure taken in *different* years, with the assumption that the first-order correlations between any two observations from consecutive years were the same; and (2) the errors correlated among different EMG measures taken in the *same* year, using a covariance structure parameterized directly from the data in terms of variances and covariances. Because of the computational complexity and our small sample, the correlation of EMG measures among the four muscles could not be accounted for or else the models would not converge. PROC MIXED in SAS allows repeated measures analysis in the presence of missing values, assuming that the values are missing at random. With this approach, no exclusion of subjects was needed because of missing data.

Our modeling proceeded in steps. First, base models examined the change of APDF 50, APDF90 and gap-time (the three dependent variables) across 3 years. All base models included year, an indicator variable to distinguish each of the three EMG measures, and an interaction term between year and the year indicator variable to assess whether the rates of change in different EMG measures over time were different.

Base model

$$Y_{ijk} = \beta_0 + \beta_1 \text{year} + \beta_2 \text{EMG Measure indicator} + \beta_3 \text{year} \times \text{EMG Measure indicator} + e_{ijk}$$

where Y_{ijk} is the EMG measures in the

*i*th year ($i = 1, 2, 3$ to identify year 1999, 2000, 2001) of *j*th EMG measure ($j = 1, 2, 3$ to identify APDF50, APDG90 and gaptime) from
*k*th subject ($k = 1, 2, 3 \ldots 33$) in study sample;
Year = 1999, 2000, or 2001;
EMG Measure Indicator = APDF50, APDF90, or gaptime.

Then non-EMG exposure independent variables from the *i*th year were added to the base models to assess whether each variable explained variation in the three EMG measures across years.

Full model

$$\begin{aligned} Y_{ijk} = {} & \beta_0 + \beta_1 \text{year} + \beta_2 \text{EMG measure indicator} \\ & + \beta_3 \text{year} \times \text{EMG measure indicator} \\ & + \beta_4 \text{non-EMG exposure}_1 \\ & + \ldots \beta_u \text{non-EMG exposure}_v + e_{ijk} \end{aligned}$$

The values for gaptime were reversed i.e. GAPTIME $*(-1)$ to accommodate the opposite trends in APDF and gaptime coefficients observed during modeling, but reversed back when presenting the results to make the directions more understandable. With two muscle sites on each side (i.e. four sites, which we henceforth refer to simply as 'muscles') and five sets of EMG data (one entire record and four task-specific), 20 (4 × 5) multivariate models resulted.

When modeling the role of non-EMG independent variables in predicting EMG measure dependent variables all independent variables from one domain e.g. equipment and dimensions was the starting point. For equipment, work organization, task, and relative fit models, EMG of all four muscle-side sites were used as dependent variables, but for posture-related fit variables the focused was on particular muscles most likely to be affected e.g. left and right trapezius for head rotation angle. Given the small participant sample size, the number of independent variables was reduced in each domain guided by the magnitudes of coefficients and their associated *p* values (<0.2 included). Remaining domain specific independent variables were included in subsequent models incorporating independent variables retained from all domains. At this stage Akaike's Information Criterion Corrected (AICC), a finite-sample corrected, less biased version of AIC for small samples (Burnham and Anderson 1998), and Bayesian Information Criterion (Schwarz 1978), were used as criteria for reductions in values from the base model to the final model.

Results

Differences in EMG across years

Examining the entire record EMG descriptive data first, modest increases in mean gap-times were observed for three muscles (left and right trapezius, right ECRB; see Table 2). For one of these, the right ECRB corresponding decreases in mean amplitudes (APDFs) were noted i.e. mean gaptime went from 3.9 to 12.4 s/min, while mean APDF 50 went from 7.3 down to 5.3% MVC, consistent with the negative correlations observed for APDF 10. For the left ECRB, mean gap-time significantly decreased and mean amplitudes increased (APDF 50 & 90 significant at $p < 0.001$). Overall 9/16 of the changes in means were statistically significant according to less stringent criteria ($p < 0.1$). Standard deviations over 3 years changed for some muscles and measures, but significance was only achieved for two: APDF 50 variance increased for left ECRB and decreased for gaptime in the same muscle (see Table 2).

Explaining variation in EMG across years with non-EMG variables

In seven base models (of a possible 20) year was important, either alone or in interaction with EMG measure (see Table 3, second row in a, b & c). Interaction here means that at least one of the EMG measures showed change over time while the others may have shown no change or different change over time. At least some non-EMG exposure independent variables were important for thirteen (3 entire record, 4 keyboarding, 4 mousing, 1 deskwork alone—not shown, 1 phone work-not shown) models with improvements in fit (reductions in AICC and BIC) noted from base to final model (see bottom row of Table 3a–c). Impacts of these independent variables varied across EMG measures, mostly associated with decreases in APDF 50 and 90 values and increases in gaptimes. For entire record EMG data

Table 2 Descriptive statistics of entire record EMG across years

Muscle site	EMG measures[a]	Year			Overall across years	Equality/difference across years	
		1999 $n = 26$ Mean (SD)	2000 $n = 33$ Mean (SD)	2001 $n = 29$ Mean (SD)	Mean (SD)	Means[b] # (p value)	Variance[c] (p value)
Left ECRB (M3)	APDF10	0.05 (0.14)	0.17 (0.68)	0.14 (0.62)	0.13 (0.55)	0.15	0.58
	APDF50	1.48 (2.66)	5.36 (5.06)[d]	4.49 (4.02)	3.91 (4.39)[d]	0.001	0.06
	APDF90	14.09 (14.82)	20.79 (12.59)[d]	19.11 (15.73)	18.23 (14.47)[d]	<0.0001	0.77
	GAPTIME	31.56 (16.13)	14.77 (9.03)	17.71 (13.34)	20.70 (14.60)	<0.0001	0.02
Left trapezius (M4)	APDF10	0.69 (0.82)	0.28 (0.61)	0.48 (0.93)	0.47 (0.80)	0.03	0.41
	APDF50	3.92 (2.62)	3.32 (2.57)	3.63 (2.85)	3.60 (2.66)	0.84	0.82
	APDF90	10.23 (6.09)	10.80 (7.47)	10.45 (5.86)	10.50 (6.5)	0.80	0.56
	GAPTIME	7.98 (14.97)	12.86 (11.60)	12.64 (12.75)	11.30 (13.10)	0.27	0.71
Right ECRB (M1)	APDF10	0.98 (1.56)	0.39 (1.13)	0.43 (0.81)	0.58 (1.20)	0.07	0.57
	APDF50	7.28 (6.23)	6.51 (5.37)	5.34 (3.90)	6.35 (5.22)	0.25	0.50
	APDF90	21.12 (13.72)	22.28 (11.54)	16.94 (9.55)	21.20 (11.70)	0.05	0.37
	GAPTIME	3.92 (3.81)	11.36 (9.27)	12.44 (7.80)	9.50 (8.30)	<0.0001	0.10
Right trapezius (M2)	APDF10	0.90 (1.75)	0.74 (1.15)	0.93 (2.08)	0.85 (1.67)	0.59	0.49
	APDF50	3.84 (3.60)	5.35 (6.11)	4.53 (4.17)	4.63 (4.84)	0.08	0.26
	APDF90	10.16 (7.22)	16.44 (16.78)	11.62 (7.73)	13.00 (12.10)	0.03	0.12
	GAPTIME	9.43 (16.87)	13.67 (13.28)	16.11 (16.48)	13.20 (15.50)	0.57	0.66

[a] APDFs in % Maximum Voluntary Contraction (MVC), GAPTIME in s/min

[b] Analysis on continuous variables used SAS Mixed Model procedure

[c] Due to the small sample size in 1999 and 2001, the test may have low power

[d] Excluding subject 'SM' in 2000, who had extreme values

(Table 3a), keyboarding-specific (Table 3b) and mousing-specific EMG (Table 3c), different combinations of equipment dimensions, posture, relative fit, and task changes predicted EMG values in different muscle models. Of note is that the most consistent significance of a non-EMG independent variable across all four muscle sites was for monitor-table edge to centre screen equipment dimension in the keyboarding task. For deskwork alone and phone work, only task variables were significant (not shown in tables).

The *equipment* dimension most consistently related to EMG measures was monitor distance from the table edge to the centre of the screen—in all keyboarding-specific models, in two mousing-specific models, and in two entire record EMG models the β coefficients were negative, indicating reduced APDF 50 and 90 values and increased gaptime with increasing distance from the monitor. For example, an increase in 10 cm in table edge to screen distance was associated with a 0.6% decrease in values for APDF 50 and APDF 90 MVC from the overall means of the left trapezius values set out in Table 2. In contrast, greater monitor to seat vertical distance was associated with greater APDF 50 and 90 values and decreased gaptime in three keyboarding-specific models and two mousing-specific models, including all models involving the trapezius. Greater distance between the J key and the centre of the mouse pad (per cm) was associated with increases in APDFs and decreases in gaptime for the left trapezius muscle in both the entire record and mousing-specific models again in comparison to the overall means.

Postural variables played more of a role compared to dimension variables, although interactions had to be considered i.e. overall effect = main effect coefficient from the EMG categorical indicator variable added to interaction coefficient for each measure. Table 3 shows the results of calculations, presenting an overall change for each measure. For example, holding the left wrist in a position between 0 and 20° of extension (vs. >20°) was associated with substantial reductions in amplitudes for the left ECRB in the entire record EMG data ($\beta = 1.5–4.19 = -2.69$ for APDF 50, $\beta = 1.5–10.91 = -9.41$ or over 9% for APDF 90, in Table 3a). Compared with a grand mean of 18.2% across years for the ECRB this implies a halving of the APDF 90 with change to a less extreme wrist posture. Comparable decreases in APDF90 were observed for keyboarding (Table 3b) as well as increases in gaptime (3.6 s/min). Paradoxically *greater* head rotation angles were associated with *decreased* amplitudes and *increased* gaptime during mousing tasks in the trapezius muscles bilaterally.

Table 3 Final multivariate models predicting EMG across years

Domain	Variables	Left ECRB (β)	Left trapezius (β)	Right ECRB (β)	Right trapezius (β)
(a) Entire record EMG					
Base	Year	Significant	Not- significant	Not-significant	Not-significant
	EMG_Measure Indicator	Significant	Significant	Significant	Significant
	Year * EMG_Measure	Significant	Significant	Significant	Not-Significant
Equipment dimensions	Keyboard-height to seat (cm)	NS	NS	−0.19% MVC in APDF50 −0.19% MVC in APDF90 0.19 s/min in GAPTIME	NS (across all domains)
	Monitor-table edge to center screen (cm)	NS	−0.06% MVC in APDF50 −0.06% MVC in APDF90 0.06 s/min in GAPTIME	−0.08%MVC in APDF50 −0.08% MVC in APDF90 0.08 s/min in GAPTIME	
	Mouse-J key to center pad (cm)	NS	0.03% MVC in APDF50 0.07% MVC in APDF90 −0.36 s/min in GAPTIME	NS	
Postures	Left wrist/ulnar deviation angle (degrees)	For Angle >10: −0.06% MVC in APDF50 0.39% MVC in APDF90 7.01 s/min in GAPTIME	NS	NS	
	Left wrist extension angle (degrees)	For Angle 0–20 : −2.69% MVC in APDF50 −9.41% MVC in APDF90 −1.50 s/min GAPTIME	NS	NS	
Relative fit	Mouse (‘Not Use’ referent)	NS	NS	For ‘Yes, in box’: −2.05% MVC in APDF50 −2.05% MVC in APDF90 2.05 s/min in GAPTIME; For ‘No, outside box’: 0.60% MVC in APDF50 0.60% MVC in APDF90 −0.60 s/min in GAPTIME	
	Phone (‘With headset’ referent)	NS	NS	For Not-headset: 1.18% MVC in APDF50 3.31% MVC in APDF90 −5.18 s/min in GAPTIME	
Work organization	Work with others	−0.5% MVC in APDF50 −2.76% MVC in APDF90 0.99 s/min in GAPTIME	NS	NS	
Tasks	# of tasks	−1.43% MVC in APDF50 −1.43% MVC in APDF90 1.43 s/min in GAPTIME	0.57% MVC in APDF50 1.50% MVC in APDF90 −3.19 s/min in GAPTIME	−1.20% MVC in APDF50 −3.32% MVC in APDF90 0.49 s/min in GAPTIME	
	% Duration of deskwork	0.04% MVC in APDF50 0.04% MVC in APDF90 −0.04 s/min in GAPTIME	NS	NS	
	% Duration keyboarding	NS	−0.01% MVC in APDF50 −0.11% MVC in APDF90 −0.02 s/min in GAPTIME	NS	
Model fit	Base (AICC, BIC)	1,815.2, 1,836.9 ($n = 33$)	1,581.2, 1,602.9 ($n = 33$)	1,688.8, 1,710.5 ($n = 33$)	1,838.8, 1,860.5 ($n = 33$)
	Final (AICC, BIC)	1,474.5, 1,509.9 ($n = 31$)	1,214.6, 1,243.5 ($n = 29$)	1,434.4, 1,466.1 ($n = 31$)	1,464.3, 1,489.5 ($n = 30$)
(b) Keyboarding tasks					
Base	Year	Significant	Not significant	Not significant	Not significant
	EMG_measure indicator	Significant	Significant	Significant	Significant
	Year * EMG_measure	Significant	Not Significant	Not significant	Significant

Table 3 continued

Domain	Variables	Left ECRB (β)	Left trapezius (β)	Right ECRB (β)	Right trapezius (β)
Equipment dimensions	Keyboard support ('2 sided'—referent)	NS	NS	For 'No support': 1.27% MVC in APDFs −1.27 s/min in GAPTIME For '1-sided Support': −3.59% MVC in APDFs 3.59 s/min in GAPTIME	NS
	Monitor-table edge to center screen (cm)	−0.19% MVC in APDF50 −0.19% MVC in APDF90 0.19 s/min in GAPTIME	−0.05% MVC in APDF50 −0.14% MVC in APDF90 0.09 s/min in GAPTIME	−0.15% MVC in APDF50 −0.27% MVC in APDF90 0.24 s/min in GAPTIME	−0.07% MVC in APDF50 −0.07% MVC in APDF90 0.07 s/min in GAPTIME
	Monitor-height to seat (cm)	0.06% MVC in APDF50 0.07% MVC in APDF90 −0.65 s/min in GAPTIME	0.18% MVC in APDF50 0.06% MVC in APDF90 −0.72 s/min in GAPTIME	NS	−0.01% MVC in APDF50 0.05% MVC in APDF90 −0.97 s/min in GAPTIME
Postures	Left wrist extension angle (degree)	For angle ≤20: −2.74% MVC in APDF50 −8.34% MVC in APDF90 3.57 s/min in GAPTIME	NS	NS	NS
Relative fit	Keyboard ('Not in box'—referent)	NS	NS	For 'Yes, inside box': −2.38% MVC in APDF50 −2.38% MVC in APDF90 2.38 s/min in GAPTIME	NS
Model fit	Base (AICC, BIC)	1,570.1, 1,591.4 ($n = 33$)	1,426.6, 1,448.0 ($n = 33$)	1,515.3, 1,536.6 ($n = 33$)	1,484.6, 1,505.9 ($n = 33$)
	Final (AICC, BIC)	1,337.7, 1,364.8 ($n = 31$)	1,148.5, 1,176.6 ($n = 31$)	1,334.1, 1,360.7 ($n = 31$)	1,192.3, 1,218.1 ($n = 32$)
(c) Mousing tasks					
Base	Year	Not significant	Not significant	Not significant	Significant
	EMG_measure indicator	Significant	Significant	Significant	Significant
	Year * EMG_measure	Not significant	Not significant	Significant	Significant
Equipment dimensions	Mouse—J key to center pad (cm)	NS	0.06% MVC in APDF50 0.10% MVC in APDF90 −0.42 s/min in GAPTIME	NS	NS
	Mouse—table edge to center pad (cm)	0.05% MVC in APDF50 −0.13% MVC in APDF90 −0.45 s/min in GAPTIME	NS	−0.22% MVC in APDF50 −0.22% MVC in APDF90 0.22 s/min in GAPTIME	NS
	Monitor-table edge to center screen (cm)	NS	−0.10% MVC in APDF50 −0.10% MVC in APDF90 0.10 s/min in GAPTIME	NS	−0.10% MVC in APDF50 −0.10% MVC in APDF90 0.10 s/min in GAPTIME
	Monitor-height to seat (cm)	NS	0.64% MVC in APDF50 0.64% MVC in APDF90 −0.64 s/min in GAPTIME	NS	0.06% MVC in APDF50 0.14% MVC in APDF90 −0.97 s/min in GAPTIME
Postures	Head rotation angle (degree)	NS	−0.08% MVC in APDF50 −0.08% MVC in APDF90 0.08 s/min in GAPTIME	NS	−0.14% MVC in APDF50 −0.14% MVC in APDF90 0.14 s/min in GAPTIME
Relative fit	Mouse ('Yes, in box'—referent)	For 'No': −2.08% MVC in APDF50 −2.08% MVC in APDF90 2.08 s/min in GAPTIME	NS	For 'No': 6.05% MVC in APDF50 6.05% MVC in APDF90 −6.05 s/min in GAPTIME	For 'No': −2.60% MVC in APDF50 −2.60% MVC in APDF90 2.60 s/min in GAPTIME
Model fit	Base (AICC, BIC)	1,236.7, 1,256.2 ($n = 31$)	1,113.8, 1,133.3 ($n = 31$)	1,273.0, 1,292.6 ($n = 31$)	1,152.2, 1,171.8 ($n = 31$)
	Final (AICC, BIC)	1,104.1, 1,125.0 ($n = 28$)	922.3, 943.7 ($n = 27$)	1,152.1, 1,171.9 ($n = 28$)	1,012.2, 1,033.5 ($n = 27$)

APDF10 and GAPTIME were moderately negatively correlated, so APDF10 was not included in the multivariate models. GAPTIME values were reversed (multiplied by negative 1) for multivariate modeling and reversed back to their original signs as presented here. Changes should be compared to the mean of measures across years (2nd last column of Table 2)

NS = No variables additional to those in base model were significant

N.B. no work organization or task indicators were significant for keyboarding tasks EMG

Better *relative fit* for the mouse was associated with decreased amplitudes and increased gaptime for the right ECRB in the entire record and mousing-specific models. Poorer relative fit which was associated with decreased left ECRB and right trapezius activity in the latter model. In the model of entire record EMG data, not having a phone headset (less than optimal phone setup) was associated with the greatest difference in gaptime (decrease of 5.18 s/min), as well as overall increases in right ECRB activity (1.18% MVC in APDF 50, 3.31% in APDF 90, Table 3a). During keyboarding tasks, having a keyboard within the box was associated with improvements in all EMG indicators in the right ECRB.

For the *work organization* variable in the entire record, 'work with others', an increase of 1 (out of 10) in agreement was associated with reductions in amplitudes and increases in gaptime (almost 1 s/min) for the left ECRB. *Task* variables were important in the entire record, deskwork alone and phone EMG models (latter two not shown). In all three, the duration variables were associated with increased values of APDF 50 and APDF 90 and decreased gaptime: in the entire record model duration of deskwork for the left ECRB ($\beta = 0.04$ per %) and in the deskwork-specific model for the right ECRB ($\beta = 0.03$ per %); and duration of phone work for the right trapezius ($\beta = 0.05$) in the phone EMG model. Number of task transitions showed different associations: increases in APDF 50 and APDF 90 and decreases in gaptime during deskwork for right ECRB ($\beta = 0.02$) but vice versa during phone work for the right trapezius ($\beta = -0.016$; data not in tables).

Discussion

Non-EMG exposure variables explained variation in EMG measures in this group of office workers across the 3 years period. Further, multiple non-EMG exposure variables together produced better fitting models explaining observed EMG than any one alone. The multi-dimensional and complex nature of workplace exposures reinforces the need for multiple types of observational and other exposure measures (Mathiassen 2006; Burdoff 2010). EMG is an integrative, physiological measure, a common pathway which reflects values of a wide range of non-EMG observed variables.

The magnitudes of changes in EMG attributed to any one independent variable varied considerably. An increase in keyboard height to seat of 1 cm would, on average, reduce APDFs by 0.19% MVC i.e. <1%, similar in magnitude to that observed by Aarås et al. (1998) in their longitudinal study. Small changes in equipment dimensions were reflected in very small changes in EMG yet the design and analytical approach detected these small differences in EMG, responding to a concern raised by others (Mathiassen et al. 2002). The largest change was in values for APDF 90 for left ECRB, from 18.2 to 8.8% with less left wrist extension. Given the associations of 'bursts' of muscle activity >2% EMGmax with higher neck pain (Hanvold et al. 2010), a change of this magnitude may also be of clinical significance.

There was a consistent impact of greater monitor to table edge distance through reduced APDFs and increased gaptimes. The CAN/ISO 9241-3 (2000) standard recommends a minimum viewing distance of 400 mm. Although the eye position will likely be further from the screen than the table edge, the initial distance 270 mm possibly positioned the user too close to the screen. In later years, the screen was approximately 370 mm from the table edge which may have put more users within the recommended range of 400–740 mm aimed at improving relative fit (CSA 2000). The decreases in APDF 50 and 90 in the right ECRB with keyboard support is consistent with Aarås et al. (1998), though why one-sided support resulted in greater decreases than two-sided support is less clear.

There were challenges in obtaining complete data due to the heavy respondent burden associated with the suite of non-EMG and EMG measures during employees' work time, with no specific incentives or additional support with their work tasks. Such field data collection is different from simulated work tasks in a laboratory setting "off-line" (Madeleine et al. 2003; Steingrímsdóttir et al. 2005). Following the taxonomy described by Mathiassen et al. (2003), we call our sampling approach "continuous with post stratification into tasks", an approach which can lead to biased estimates if the tasks changed systematically over time; either over a day or week. As work in the newspaper is cyclic over a week, the recordings were made on the same day and "same time of day where possible" aiming to reduce this bias. Our statistical analysis methods also partially compensated for missing values. The measures chosen in EMG processing were a subset from a much larger potential set of choices (Jensen et al. 1998). Such selection can influence characterization of muscle activity patterns substantially (Veiersted et al. 2010). Nevertheless, we felt it necessary to reduce the already substantial concerns associated with the multiple measures of variables (both independent and dependent) across several muscles and tasks of interest. Finally, some of the directions of parameters for non-EMG exposure variables are perplexing and require clarification among a range of computer users in other settings.

Important strengths of this work included: the guidance in data collection provided by a conceptual framework which recognized multifactorial prediction of EMG; the prioritization of particular analyses of relationships between appropriate variables e.g. for posture-EMG relationships; and the multivariate approach to statistical analyses which took into account correlated measures within people (muscles) and over time (years). The limited number of studies with repeated measures in field settings and such analytical approaches makes our contribution valuable for others interested in assessing the impacts of workplace change with integrative measures such as EMG. We encourage collection of a range of observation and self-report non-EMG exposure measures longitudinally, with an emphasis on having some in each domain, to maximize explanation of EMG outcomes. We strongly encourage using multivariate analytic techniques to take into account correlations in EMG across muscles. In future studies, interpretation of coefficients would be aided by more reporting of the EMG impacts of changes in non-EMG exposure measures, as well as greater documentation of associations with measures of participant health.

The important role played by some workstation dimensions (e.g. monitor distance), and postures (e.g. wrist extension), may provide support to practitioners faced with the need to more immediately reduce office workers' exposures. Practitioners would be well advised to keep in mind results of reviews assessing effectiveness of workplace interventions among computer users (Brewer et al. 2006). In the meantime, the methods use here can provide guidance to other researchers seeking to monitor changes in office work environments, potential impacts on muscle activity, and, ultimately, reductions in MSDs among VDT-computer using office workers.

Acknowledgments The authors acknowledge contributions by: other members of the *Worksite Upper Extremity Group at the Institute for Work & Health (Dorcas Beaton, Carol Kennedy, Hyunmi Lee, Anne Moore, Michael Polanyi, Harry Shannon, Peter Subrata, Michael Swift); labour and management members of the RSI (Repetitive Strain Injury) Committee at the workplace; and participants in the study. The Institute for Work & Health, an independent not-for-profit research organization, sponsored the study and in turn receives support from the Ontario Workplace Safety & Insurance Board. Specific funding for the physical measures work was provided by the RSI Committee, the John's Hopkins' Center for VDT & Health and the U.S. National Institute for Occupational Safety and Health/National Institutes of Health (Research Grant #5 R01 OH003708-03). None of the authors has ongoing relationships with either the union or company involved.

Conflicts of interest Other than those relationships described in the Acknowledgements, the authors declare that they have no conflicts of interest.

References

Aarås A, Horgen F, BjØrset H, Ro O, Thoresen M (1998) Musculoskeletal, visual and psychosocial stress in VDU operators before and after multidisciplinary ergonomic interventions. Appl Ergonomics 29(5):335–354

Beech-Hawley L, Wells R, Cole DC (2004) A multi-method approach to assessing deadlines and workload variation among newspaper workers. Work 23(1):43–58

Brewer S, Van Eerd D, Amick BC, Irvin E, Daum KM, Gerr F et al (2006) Workplace interventions to prevent musculoskeletal and visual symptoms and disorders among computer users: a systematic review. J Occup Rehabil 16(3):325–358

Bruno JL, Huysmans MA, Dennerlein JT (2010) Accounting for individual variability improves estimates of biomechanical parameters in computer workers. In: Abstract presented at PREMUS the 7th International conference on prevention of work-related musculoskeletal disorders, Angers, France, Aug 29th–Sept 2, p 281

Burdoff A (2010) The role of assessment of biomechanical exposure at the workplace in the prevention of musculoskeletal disorders. Scand J Work Environ Health 36(1):1–2

Burnham KP, Anderson DR (1998) Model selection and inference: a practical information-theoretic approach. Springer, New York

Canadian Standards Association (CSA) (2000) CAN/CSA-ISO 9241-3A-00 ergonomic requirements for office work with visual display terminals (VDTs)—part 3: visual display requirements (adopted amendment 1:2000 to ISO 9241-3:1992), CSA, Toronto, Canada

Cole DC, Wells RP, The Worksite Upper Extremity Research Group (2002) Interventions for musculoskeletal disorders in computer intense office work: a framework for evaluation. Work Stress 16:95–106

Cole DC, Hogg-Johnson S, Manno M, Ibrahim S, Wells RP, Ferrier SE, The Worksite Upper Extremity Research Group (2006) Reducing musculoskeletal burden through ergonomic program implementation in a large newspaper. Int Arch Occup Environ Health 80:98–108

Cole DC, Van Eerd D, Wells RP, Chen C, Hogg-Johnson S (2010) Workplace intervention associated changes in office environment and worker-environment interface indicators at a large newspaper. Working Paper # 351. Toronto, ON, Canada: Institute for Work & Health. June. Accessible through http://www.iwh.on.ca

Engström T, Medbo P (1997) Data collection and analysis of manual work using video recording and personal computer techniques. Int J Ind Ergon 19:291–298

Forsman M, Hansson G-Å, Medbo L, Asterland P, Engström T (2002) A method for evaluation of manual work using synchronized video recordings and physiological measurements. Appl Ergonomics 33:533–540

Gao F, Thompson P, Xiong C, Miller JP (2006) Analyzing multivariate longitudinal data using SAS. SUGI 31, paper 187–31. http://www2.sas.com/proceedings/sugi31/187-31.pdf#search=%22analyzing%20multivariate%20longitudinal%20data%2C%20feng%20gao%22. Accessed September 2006

Gerr F, Marcus M, Ensor C, Kleinbaum D, Cohen S, Edwards A et al (2002) A prospective study of computer users: I. Study design and incidence of musculoskeletal symptoms and disorders. Am J Ind Med 41:221–235

Hansson G-Å, Balogh I, Unge Byström J, Ohlsson K, Nordander C, Asterland P et al (2001) Questionnaire versus direct technical measurements in assessing postures and movements of the head, upper back, arms and hands. Scand J Work Environ Health 27(1):30–40

Hansson G-Å, Balogh I, Ohlsson K, Granqvist L, Nordander C, Arvidsson I et al (2009) Physical workload in various types of work: Part I. Wrist and forearm. Int J Ind Ergon 39:221–233

Hansson G-Å, Balogh I, Ohlsson K, Granqvist L, Nordander C, Arvidsson I et al (2010) Physical workload in various types of work: part II. Neck, shoulder and upper arm. Int J Ind Ergon 40:267–281

Hanvold TN, Veiersted KB, Waersted M (2010) Sustained trapezius muscle activity and development of neck pain in young workers. In: Abstract presented at PREMUS the 7th International Conference on Prevention of Work-Related Musculoskeletal Disorders, Angers, France, Aug 29th–Sept 2, p 177

Holte KA, Westgaard RH (2002) Daytime trapezius muscle activity and shoulder-neck pain of service workers with work stress and low biomechanical exposure. Am J Ind Med 41:393–405

Homan MM, Armstrong TJ (2003) Evaluation of three methodologies for assessing work activity during computer use. Am Ind Hygiene Assn J 64:48–55

Huis in 't Veld RMH, Huijgen BCH, Schaake L, Hermens HJ, Vollenbroek-Hutten MMR (2008) A staged approach evaluation of remotely supervised myofeedback treatment (RSMT) in women with neck–shoulder pain due to computer work. Telemed E-Health 14(6). doi:10.1089/tmj.2007.0090

Jensen C, Borg V, Finsen L, Hansen K, Juul-Kristensen B, Christensen H (1998) Job demands, muscle activity and musculoskeletal symptoms in relation to work with the computer mouse. Scand J Work Environ Health 24(5):418–424

Jonsson BG, Persson J, Kilbom Å (1988) Disorders of the cervicobrachial region among female workers in the electronics industry: a two-year follow up. Int J Ind Ergo 3:1–12

Karlqvist LK, Bernmark E, Ekenvall L, Hagberg M, Isaksson A, Rostö T (1998) Computer mouse position as a determinant of posture, muscular load and perceived exertion. Scand J Work Environ Health 24(1):62–73

Levene H (1960) Robust tests for equality of variances. In: Olkin I et al. (eds) Contributions to probability and statistics: essays in honor of Harold Hotelling. Stanford University Press, Stanford, pp 278–292

Madeleine P, Lundager B, Voigt M, Arendt-Nielsen L (2003) The effects of neck–shoulder pain development on sensory–motor interactions among female workers in the poultry and fish industries. A prospective study. Int Arch Occup Environ Health 76:39–49. doi:10.1007/s00420-002-0375-8

Marcus M, Gerr F, Monteilh C et al (2002) A prospective study of computer users: II postural risk factors for musculoskeletal symptoms and disorders. Am J Ind Med 41:236–249

Mathiassen SE (2006) Diversity and variation in biomechanical exposure: why is it, and why would we like to know? Appl Ergonomics 37:419–427

Mathiassen SE, Burdorf A, van der Beek AJ (2002) Statistical power and measurement allocation in ergonomic intervention studies assessing upper trapezius EMG amplitude—a case study of assembly work. J Electromyogr Kinesiol 12:45–47

Mathiassen SE, Burdorf A, van der Beek AJ, Hansson G-Å (2003) Efficient 1-day sampling of mechanical job exposure data—a study based on upper trapezius activity in cleaners and office workers. AIHA J 64(2):196–211

Moore A, Wells R, Van Eerd D, Banina M, Cole DC, Hogg-Johnson S (2003) Separation and summation of EMG recordings by task using video records. In: Proceedings of the society's 2003 Congress XIX conference

Østensvik T, Veiersted KB, Nilsen P (2009) Association between numbers of long periods with sustained low-level trapezius muscle activity and neck pain. Ergonomics 52:1556–1567

Polanyi MFD, Cole DC, Beaton DE et al (1997) Upper limb work-related musculoskeletal disorders among newspaper employees: cross-sectional survey results. Am J Ind Med 32:620–628

Sandsjö L, Kadefors R (2001) Prevention of muscle disorders in computer users: scientific basis and recommendations. In: Sandsjö L, Kadefors R (eds) Proceedings of the 2nd PROCID symposium, prevention of muscle disorders in computer users: scientific basis and recommendations. National Institute for Working Life/West, Göteborg, Sweden, 8–10 March

SAS V9.0 (2002-3). SAS Institute Inc., Cary

Schwarz G (1978) Estimating the dimension of a model. Ann Stat 6:461–464

Steingrímsdóttir OA, Vøllestad NK, Knardahl S (2005) A prospective study of the relationship between musculoskeletal or psychological complaints and muscular responses to standardized cognitive and motor tasks in a working population. Eur J Pain 9:311–324

Sundelin G, Hagberg M (1989) The effects of different pause types on neck and shoulder EMG activity during VDU work. Ophthal Physiol Opt 32:527–537

Tornqvist EW, Hagberg M, Hagman M, Risberg EH, Toomingas A (2009) The influence of working conditions and individual factors on the incidence of neck and upper limb symptoms among professional computer users. Int Arch Occup Environ Health 82:689–702. doi:10.1007/s00420-009-0396-7

van den Heuvel SG, van der Beek AJ, Blatter BM, Bongers PM (2006) Do work-related physical factors predict neck and upper limb symptoms in office workers? Int Arch Occup Environ Health 79:585–592. doi:10.1007/s00420-006-0093-8

Van Eerd D, Hogg-Johnson S, Mazumder A, Cole D, Wells R, Moore A (2009) Task exposures in an office environment: a comparison of methods. Ergonomics 52:1248–1258

Van Eerd D, Hogg-Johnson S, Cole DC, Wells R (submitted) Comparison of occupational exposure methods relevant to musculoskeletal disorders: worker-workstation interaction in an office environment. J Electromyogr Kinesiol

Veiersted KB, Westgaard RH, Andersen P et al (1993) Electromyographic evaluation of muscular work pattern as a predictor of trapezius myalgia. Scand J Work Environ Health 19:284–290

Veiersted KB, Forsman M, Mathiassen SE (2010) Comparison of time and level based EMG parameters for assessments of muscle activity patterns. In: Abstract presented at PREMUS, the 7th international conference on prevention of work-related musculoskeletal disorders, Angers, France, 29 Aug–2 Sept, p 175

Wells R, Van Eerd D, Hägg G (2004) Mechanical exposure concepts using force as the agent. Scan J Work Environ Health 30:179–190

Westgaard RH, Aarås A (1985) The effect of improved workplace design on the development of work-related musculoskeletal illnesses. Appl Ergonomics 16(2):91–97