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## Relationships between job organisational factors, biomechanical and psychosocial exposures

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The relationships between work organisational, biomechanical and psychosocial factors were studied using cross-sectional data from a pooled dataset of 1834 participants. The work organisational factors included: job rotation, overtime work, having second jobs and work pace. Task and job level biomechanical variables were obtained through sub-task data collected in the field or analysed in the laboratory. Psychosocial variables were collected based on responses to 10 questions. The results showed that job rotations had significant effects on all biomechanical and most psychosocial measures. Those with job rotations generally had higher job biomechanical stressors, and lower job satisfaction. Overtime work was associated with higher job biomechanical stressors, and possibly self-reported physical exhaustion. Those having second jobs reported getting along with co-workers well. Work pace had significant influences on all biomechanical stressors, but its impact on job biomechanical stressors and psychosocial effects are complicated.

**Practitioner Summary:** The findings are based on a large number of subjects collected by three research teams in diverse US workplaces. Job rotation practices used in many workplaces may not be effective in reducing job biomechanical stressors for work-related musculoskeletal disorders. Overtime work is also associated with higher biomechanical stressors.

**Keywords:** work-related musculoskeletal disorders; job risk assessment; job rotation; work pace; overtime work

### Introduction

Work-related musculoskeletal disorders (WMSDs) are a major health problem among many employed workers, responsible for a significant proportion of occupational morbidity, lost work days and cost (Roquelaure et al. 2004; Shiri et al. 2006; Silverstein et al. 2006; Occhionero, Korpinen, and Gobba 2014). According to Washington State workers compensation claims data, WMSDs accounted for approximately 41% of all compensable claims in the services sector and had the highest compensable claim rates among all work-related compensable claims (Anderson, Bonauto, and Adams 2014). In one automotive manufacturing company, the payroll cost of all back and shoulder disorders was at least US\$320 per year per worker, not including workers' compensation premiums or claims paid (Punnett 1999).

As WMSDs affect the bottom line of many businesses, ergonomics intervention efforts have been attempted by many companies (Roquelaure et al. 2004; Rivilis et al. 2006; Fathallah 2010; Choi 2012; Levanon et al. 2012). Ergonomics interventional research has also sought to identify key elements that may make ergonomics interventions effective, efficient and sustainable (Silverstein and Clark 2004; Hignett, Wilson, and Morris 2005; St-Vincent et al. 2006; Haukka et al. 2008; Van Eerd et al. 2008; Garg and Kapellusch 2012). Ergonomics interventions often focus on modifying certain aspects of a production system to improve attributes associated with or known to be risk factors for WMSDs. For example, interventions may be aimed at reducing biomechanical exposures via modifying work stations (Drury et al. 2008; Draicchio et al. 2012), providing improved tools (Stal, Pinzke, and Hansson 2003; Earle-Richardson et al. 2005) and making appropriate work method changes (Hakkanen, Viikari-Juntura, and Takala 1997), or other interventions may try to influence multiple aspects in an organisation that may result in improvements in both biomechanical and psychosocial exposures (Feuerstein et al. 2000; Caple 2007; Szeto et al. 2013).

To implement effective, efficient and sustainable ergonomics interventions, it is important to understand how the way work is organised influences workers' biomechanical exposures, and psychosocial stresses, and the relationships between these factors. Several researchers have proposed causation models that often include biomechanical exposure, work organisational and psychosocial factors (Carayon, Smith, and Haims 1999). A simplified model is shown in Figure 1. Work

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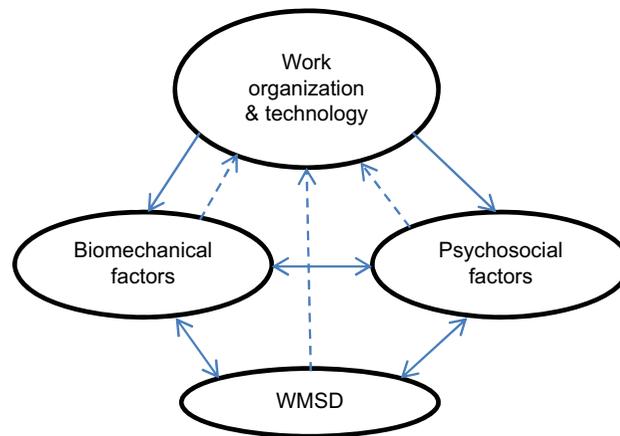


Figure 1. A simplified causation model between work organisation, biomechanical exposure, psychosocial factors and work-related musculoskeletal disorders (WMSD) – Work organisation and technology determine biomechanical stressors on the workers and influence their psychosocial factors. These biomechanical and psychosocial exposures may result in or be associated with different musculoskeletal health consequences. These exposures and musculoskeletal health status of the workers may also influence the changes in work organisation and technology.

organisation and technology in this model include all aspects of a production system or organisation where products are made or services are provided using a set of technologies and machines, in organised processes. These workplace factors determine the external exposures that are experienced by the workers. These external exposures may have various biomechanical and psychosocial effects on the workers [or the internal exposures on the workers (Winkel and Mathiassen 1994)]. These biomechanical and psychosocial exposures may result in or be associated with different musculoskeletal health consequences (MSDs, discomfort, and workers' compensation claims related to WMSDs). A prior publication by this research group has explored the relationships between individual psychosocial factors and job physical exposures (Thiese et al. 2015).

Understanding the conceptual model is important in helping management make informed decisions aimed at improving productivity and competitiveness while reducing injuries and costs.

While the model may be comprehensible, more field data are needed to establish quantitative relationships. A consortium of work-related upper extremity MSDs has built a database including detailed prospective information on work organisational, biomechanical exposures and psychosocial variables of individual workers from diverse US industries. The broad scope of jobs ranged from less physical activity jobs such as office workers, pharmacists and light electronic assembly jobs to very physically demanding jobs such as sawmill workers, and heavy mechanical assembly jobs (Bao et al. 2015). A subset of this database has detailed sub-task biomechanical exposure variables, psychosocial variables of individual workers as well work organisational variables.

The objective of this study was to use the baseline cross-sectional data of this consortium dataset to explore the relationships between several work organisational, biomechanical and psychosocial variables. This is the initial attempt to study the relationships. Further detailed prospective analysis will follow in near future.

## Materials and methods

The data sources were three study cohorts collected by the University of Wisconsin-Milwaukee (UWM), University of Utah (UU) and Department of Labor and Industries of the State of Washington (LNI). These studies were approved by the respective Institutional Review Boards (IRB). The data pooling process was coordinated by UWM and approved by its IRB. Although the pooled data are prospective in nature, only the baseline data will be used for the analyses of this exploratory analysis.

Similar procedures were used by the three research teams to collect work organisational, biomechanical and psychosocial variables (Bao et al. 2015). Details of data collection methods can be found from several of our previous publications (Bao et al. 2006; Howard et al. 2009; Smith et al. 2009; Garg, Hegmann, et al. 2012). The work organisational, biomechanical exposure and psychosocial variables used in this study are summarised below. Some variables were obtained through questionnaire, while others were quantified from direct observation. All questions were thoroughly pilot tested for both comprehension and efficiency.

### **Work organisational variables**

Four work organisational variables were used in the analyses: (1) job rotation, (2) working overtime, (3) having second job (s) and (4) work pace.

'Job rotation' is a dichotomised variable. This variable was obtained through interview and observation during worksite visits. When a worker was assigned with more than one single task for a period of time in his or her job during a work shift, the worker was identified as having job rotation. This was verified during worksite visit.

'Working overtime' is also a dichotomised variable. It was defined as working more than 40 h per week. This variable was obtained through interviews or questionnaires.

'Working a second job' was also a dichotomous variable. It was defined as having a second job with another employer as reported by the subjects themselves. This variable was obtained using questionnaires. A worker without a second job means that the worker only performed the current job with the studied employer.

'Work pace' is a trichotomous variable. The work pace variable was collected by analyst observations during worksite visits. This variable was grouped into three categories: machine paced (including line paced and paced by social peer), worker self-paced and piece rate (including work by quota). The work pace variable was determined by the workstation at which a worker performed a specific task. It is a task specific variable. Therefore, it was used to study relationships with task level biomechanical exposure variables. For the job-level analyses in this study, the work pace corresponding to the longest task was used, if a worker has more than one tasks in his/her job (having job rotation).

### **Biomechanical exposure variables**

Biomechanical exposures for each worker were collected at the sub-task level. They included: (1) forceful exertions, (2) repetitions, (3) duration of exertions and (4) hand/wrist postures. The sub-task data were collected on site in workplaces through observations and video recordings. Video processing/observations were subsequently completed in laboratories. An overall force level was self-reported by workers and also estimated by analysts. Repetition was estimated using the scale from the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV) for Hand Activity Level (HAL) (Latko et al. 1997; ACGIH 2001) and also quantified from frequency of exertions with video analyses. These measures of force and repetition were used to quantify the sub-task biomechanical exposure data. Two different exertions were defined: (1) any exertions including very low force exertions, and (2) forceful exertions when the analyst rated the force level was greater than or equal to 2 using the Borg scale (Borg 1982).

The sub-task exposure data were integrated to obtain job level exposure variables. Three commonly used data reduction approaches were employed: (1) time-weighted averaging (TWA) – weights were assigned based on the amounts of time that sub-tasks have in a task and job and exposure value was calculated by time-weighted averaging of all sub-task exposures, (2) typical approach – value of the exposure corresponding to the sub-task with the longest duration in a task and job was used, (3) peak value approach – the highest sub-task exposure value in a task or job was used. The following task and job level exposure variables were derived after the data reduction computations:

#### Force variables

- Peak force (job) – Peak force at the *job level* using peak value from all sub-tasks based on analyst estimated hand force
- Peak force (task/analyst) – Peak force at the *task level* using peak from all sub-tasks based on analyst estimated hand force
- Peak force (task/worker) – Peak force at the *task level* using peak from all sub-tasks based on worker self-reported hand force

#### Repetition and duration variables

- HAL (TWA) – Hand activity level using TWA computation (*job level*)
- HAL (peak) – Hand activity level using peak value from all tasks (*job level*)
- HAL (typical) – Hand activity level using typical value from all tasks (*job level*)
- HAL (task) – Hand activity level rating for individual task (*task level*)
- Effort/min (Borg  $\geq 2$ , TWA) – Effort per minute for forceful exertions of Borg scale  $\geq 2$ , using TWA computation (*job level*)
- Effort/min (Borg  $\geq 2$ , peak) – Effort per minute for forceful exertions of Borg scale  $\geq 2$ , using peak value computation (*job level*)
- Effort/min (Borg  $\geq 2$ , typical) – Effort per minute for forceful exertions of Borg scale  $\geq 2$ , using typical value computation (*job level*)

- Effort/min (all, task) – Effort per minute for all exertions (regardless of their exertion level) at *task level*
- Effort/min (Borg  $\geq 2$ , task) – Effort per minute for forceful exertions of Borg scale  $\geq 2$  at *task level*
- DC (Borg  $\geq 2$ , TWA) – Duty cycle for forceful exertions of Borg scale  $\geq 2$ , using TWA computation (*job level*)
- DC (Borg  $\geq 2$ , peak) – Duty cycle for forceful exertions of Borg scale  $\geq 2$ , using peak value computation (*job level*)
- DC (Borg  $\geq 2$ , typical) – Duty cycle for forceful exertions of Borg scale  $\geq 2$ , using typical value computation (*job level*)
- DC (all, task) – Duty cycle for all exertions (regardless of their exertion level) at *task level*
- DC (Borg  $\geq 2$ , task) – Duty cycle for forceful exertions of Borg scale  $\geq 2$  at *task level*

Hand/wrist posture and other variables (these variables were used for the job evaluation analyses)

- HW posture – Hand/wrist posture rated on the Strain Index (Moore and Garg 1995) scale (*task level*)
- Speed of work – Speed of work rated on the Strain Index scale (*task level*)

The Strain Index (Moore and Garg 1995) and ACGIH TLV for HAL methods (ACGIH 2001) were used to quantify job biomechanical stressors by considering the combining effects of forceful exertions, exertion repetition and duration and hand/wrist postures. Several variant calculations were performed using TWA, peak and typical values of required exposure variables respectively. The following biomechanical stressor variables were derived from these job physical data:

- SI (TWA) – Strain Index using TWA computation,
- SI (typical) – Strain Index using typical computation,
- SI (peak) – Strain index using peak computation,
- TLV for HAL (TWA) – ACGIH TLV for HAL using TWA computation,
- TLV for HAL (typical) – ACGIH TLV for HAL using typical computation, and
- TLV for HAL (peak) – ACGIH TLV for HAL using peak computation.

### ***Psychosocial variables***

The psychosocial variables were collected using questionnaires. A total of 10 variables were included in the analyses. These variables with category values were obtained by the following 10 questions:

- *General health* – How would you describe your general health compared to other of your own age? (1: much better, 2: somewhat better, 3: the same, 4: somewhat worse, or much worse)
- *Depressed* – How often during the past year have you felt ‘down’ blue or depressed? (1: never, 2: seldom, 3: often, 4: always)
- *Physically exhausted* – How often are you physically exhausted after work? (1: never, 2: some of the time, 3: often, 4: always)
- *Mentally exhausted* – How often are you mentally exhausted after work? (1: never, 2: some of the time, 3: often, 4: always)
- *Get along with co-workers* – Do you get along with your co-workers? (1: almost always, 2: some of the time, 3: hardly ever)
- *Satisfactions with job* – All in all, how satisfied are you with your job? (1: satisfied, 2: somewhat satisfied, 3: dissatisfied)
- *Get along with supervisor* – I get along well with my closest or immediate supervisor. (1: almost always, 2: some of the time, 3: hardly ever)
- *Recommend job to others* – How strongly would you recommend your job to someone else? (1: strongly recommend, 2: recommend, 3: neither recommend nor discourage, 4: not recommend at all)
- *Take this job again* – If you were looking for a new job now, how likely is it that you would decide to take this job again? (1: very likely, 2: somewhat likely, 3: neither likely nor unlikely, 4: very unlikely)
- *Employer cares about health and safety* – My employer cares about my health and safety on the job. (1: strongly agree, 2: agree, 3: disagree, 4: strongly disagree)

### ***Statistical analyses***

Descriptive statistics were calculated for all work organisational, biomechanical and psychosocial variables in order to determine their distribution characteristics. Correlation analyses were performed among the job biomechanical exposure data and psychosocial variables.

Bivariate analyses were carried out to assess the association between work organisational and biomechanical exposure variables, and between work organisational and psychosocial variables. For the continuous biomechanical exposure variables, the median values of the corresponding biomechanical exposure variables for the different work organisation variable categories were calculated. Kruskal–Wallis tests were used to assess differences in the mean ranks of the respective biomechanical exposure variables in the different work organisational variable categories. For the categorical psychosocial variables, frequencies and proportions of occurrences of the different categories were calculated. Odds ratios were calculated to evaluate responses to the different psychosocial questions for different work organisational variable categories.

For the analysis of work pace at the task level, median values of the task level biomechanical variables were calculated. Kruskal–Wallis tests were used to assess differences in the mean ranks of the respective biomechanical exposure variables in the three categories of work pace variable. Pairwise comparisons were performed in the post hoc analyses using Dwass, Steel, Critchlow-Fligner (DSCF) multiple comparison analysis.

All analyses were performed using SAS 9.4 software (Cary, NC, USA). Statistically significant differences were defined when  $P < 0.05$ .

## Results

Overall, there were 1834 participants (male: 738 or 40.2%; female: 1096 or 59.8%) in the pooled dataset at the baseline. Only baseline data will be used in the present analyses. The average age of the participants was 41.1 years. Men were significantly ( $P < 0.0001$ ) older (mean: 43.3 years) compared to the women (mean: 38.0 years). The male participants reported a mean current job tenure of 7.0 years compared to 9.5 years for the female participants ( $P < 0.0001$ ). Table 1 shows the characteristics of the participants from the three cohorts.

In the pooled dataset, 710 workers (or 38.7%) had job rotations (i.e.  $\geq 2$  tasks in a job), and 1124 (or 61.3%) had only one task during a workday. The majority of workers (1460 or 79.6%) did not work overtime ( $\leq 40$  h/week), and only 20.4% (or 374) worked overtime ( $> 40$  h/week). Many participants (419) did not have information on having a second job. Of those with this information, a small group of workers (137 or 9.7%) reported having a second job, while the majority (678 or 92.5%) had only one job. For those who had more than one task in his/her job, the work pace type corresponding to the task with the longest duration was used to represent the work pace type at the job level. Approximately half of the jobs were machine-paced (851 or 46.7%) and the other half were self-paced (876 or 48.0%). A small group of participants (97 or 5.3%) worked at piece rate and 10 participants did not have information on the work pace variable.

Most of the biomechanical variables were not normally distributed, rather they were skewed. Correlation analyses showed that ‘*employer cares about health and safety*’ and ‘*depressed*’ were moderately correlated (Pearson product–moment correlation coefficient,  $r = 0.48$ ). ‘*Mentally exhausted*’ was moderately correlated with ‘*physically exhausted*’ ( $r = 0.43$ ). Several variables related to job satisfaction (‘*recommend job to others*’, ‘*satisfaction with job*’ and ‘*take this job again*’) were moderately correlated as well ( $r = 0.55$ – $0.61$ ). Neither ‘*mentally exhausted*’ nor ‘*physically exhausted*’ had correlations with any of the job biomechanical measures (TLV for HAL (typical) and SI (typical) with  $r = -0.06$ – $0.05$ ). There was slight correlation between the work pace and overtime work (Pearson correlation coefficient = 0.18,  $P < 0.0001$ ). More piece rate jobs had overtime work than machine-paced jobs. Correlation analysis showed that those with job rotations were slightly more likely being machine-paced (Pearson correlation coefficient =  $-0.15$ ,  $P < 0.0001$ ).

Table 1. Characteristics of the participants from the three cohorts.

	UWM	UU	LNI	Total
Number of subjects	769	332	733	1834
% of male subjects	31.7	33.4	52.3	40.2
Mean age (years)	42.3 (11.5)	42.9 (11.0)	39.1 (11.0)	41.1 (11.3)
Seniority at job (years)	10.6 (10.0)	9.3 (7.3)	6.2 (6.8)	8.5 (8.5)
Mean weight (kg)	81.3 (21.0)	82.3 (22.0)	79.8 (19.9)	80.9 (20.8)
Mean height (m)	1.66 (0.09)	1.65 (0.10)	1.71 (0.11)	1.68 (0.10)
Mean BMI (body mass index)	29.3 (6.6)	30.0 (7.1)	27.3 (5.8)	28.7 (6.5)
% of right-handed subjects	91.7	93.4	91.5	91.9

Note: Standard deviation in parentheses.

### Job rotation

Job rotation had statistically significant effects on all biomechanical stressors (Table 2). Those with job rotations had higher job biomechanical stressors (whether quantified using the Strain Index or the ACGIH TLV for HAL) and higher exposure levels (force, repetition and duration variables) based on their Wilcoxon ranking scores. The median values of the biomechanical stressors for those of with and without job rotation groups provide some indications on the effect sizes. For example, using peak force value in the Strain Index calculation resulted in larger effect compared to that using the time-weighted-average force value (8.5/1.5 vs. 4.0/1.5, Table 2).

Job rotation was also statistically significantly associated with several psychosocial measures (Table 3). Those with job rotation generally reported lower job satisfaction – (1) they were more likely not to ‘recommend their jobs to others’ (odds ratio (OR): 1.31), (2) more likely to report ‘dissatisfaction with their jobs’ (OR: 1.65), (3) more unlikely to ‘take the same jobs again’ (OR: 1.63), (4) more likely to disagree that their ‘employer cared about their health and safety’ (OR: 1.39) and (5) more likely to report hardly ever ‘getting along with their supervisors’ (OR: 1.36).

### Overtime work

Overtime work had statistically significant associations with many of the biomechanical stressors (Table 2). Those who had overtime work usually had higher job biomechanical stressors as measured by the Strain Index method. However, when the biomechanical stressors were evaluated using the ACGIH TLV for HAL, this relationship

Table 2. Relationships between work organisation variables and job level biomechanical exposures.

Biomechanical exposure	Value	Job rotation		Working over time		Having a second job	
		Median	$P > \chi^2$	Median	$P > \chi^2$	Median	$P > \chi^2$
Number of subjects		1834		1834		1415	
SI (typical)	No	1.5	< 0.0001	3.0	< 0.0001	2.3	0.19
	Yes	6.0		6.0		3.0	
SI (TWA)	No	1.5	< 0.0001	2.3	< 0.0001	2.2	0.13
	Yes	4.0		5.4		2.7	
SI (Peak)	No	1.5	< 0.0001	3.0	< 0.0001	3.0	0.27
	Yes	8.5		6.0		3.0	
TLV for HAL (TWA)	No	0.33	< 0.0001	0.38	0.22	0.38	0.97
	Yes	0.42		0.38		0.38	
TLV for HAL (Peak)	No	0.33	< 0.0001	0.43	0.44	0.43	0.99
	Yes	0.60		0.50		0.43	
TLV for HAL (typical)	No	0.33	< 0.0001	0.43	0.20	0.41	0.89
	Yes	0.60		0.50		0.40	
Peak force (job)	No	3.0	< 0.0001	3.0	< 0.0001	3.0	0.55
	Yes	2.5		2.0		3.0	
HAL (TWA)	No	4.0	< 0.0001	4.0	< 0.0001	4.0	0.25
	Yes	4.5		4.8		4.5	
HAL (Peak)	No	4.0	< 0.0001	5.0	< 0.0001	4.0	0.11
	Yes	6.0		6.0		5.00	
HAL (typical)	No	4.0	< 0.0001	5.0	< 0.0001	4.0	0.66
	Yes	6.0		6.0		5.00	
Effort/min, (Borg $\geq$ 2, TWA)	No	1.9	< 0.0001	3.3	0.45	3.1	0.36
	Yes	5.8		3.9		3.4	
Effort/min, (Borg $\geq$ 2, Peak)	No	1.9	< 0.0001	4.3	0.095	3.9	0.46
	Yes	11.8		6.0		4.0	
Effort/min (Borg $\geq$ 2, typical)	No	1.9	< 0.0001	3.9	0.040	3.6	0.36
	Yes	10.0		5.9		3.9	
DC (Borg $\geq$ 2, TWA)	No	9.4	< 0.0001	14.7	0.74	13.4	0.43
	Yes	20.9		13.4		14.1	
DC (Borg $\geq$ 2, Peak)	No	8.3	< 0.0001	19.9	0.31	18.8	0.70
	Yes	39.1		22.6		18.6	
DC (Borg $\geq$ 2, typical)	No	9.4	< 0.0001	18.2	0.14	17.0	0.52
	Yes	32.7		21.7		17.8	

Note: Median, bold – statistically significant at  $P = 0.05$ , Kruskal–Wallis test). TWA, Time Weighted Average; HAL, Hand Activity Level; TLV, Threshold Limit Value; DC, Duty Cycle; Borg, Borg Perceived Exertion Scale (Borg 1982).

Table 3. Job rotation and psychosocial variables, frequency (proportion) and odds ratio (higher rating to lower rating).

Psychosocial variable (rating scale direction)	N	Job rotation	Psychosocial variable rating				OR (95% CI)
			1	2	3	4	
Employer cares about health and safety (strongly agree – strongly disagree)	1834	No	<b>300 (26.7%)</b>	<b>694 (61.7%)</b>	<b>90 (8.0%)</b>	<b>40 (3.6%)</b>	<b>1.39 (1.15–1.68)</b>
		Yes	<b>150 (21.1%)</b>	<b>446 (62.8%)</b>	<b>86 (12.1%)</b>	<b>28 (3.9%)</b>	
Depressed (never – always)	1834	No	325 (28.9%)	617 (54.9%)	167 (14.9%)	15 (1.3%)	1.14 (0.95–1.37)
		Yes	180 (25.4%)	411 (57.9%)	102 (14.4%)	17 (2.4%)	
General health (much better – much worse)	1834	No	159 (14.1%)	391 (34.8%)	459 (40.8%)	115 (10.2%)	1.03 (0.86–1.22)
		Yes	104 (14.6%)	240 (33.8%)	284 (40.0%)	82 (11.5%)	
Get along with co-workers (almost always – hardly ever)	1834	No	588 (52.3%)	441 (39.2%)	95 (8.5%)		1.03 (0.86–1.23)
		Yes	359 (50.6%)	304 (42.8%)	47 (6.6%)		
Recommend job to others (strongly recommend – not recommend at all)	1834	No	<b>176 (15.7)</b>	<b>575 (51.2%)</b>	<b>252 (22.4%)</b>	<b>121 (10.8%)</b>	<b>1.31 (1.10–1.56)</b>
		Yes	<b>102 (14.4%)</b>	<b>319 (44.9%)</b>	<b>183 (25.8%)</b>	<b>106 (14.9%)</b>	
Satisfaction with job (satisfied – dissatisfied)	1834	No	<b>361 (32.1%)</b>	<b>572 (50.9%)</b>	<b>191 (17.0%)</b>		<b>1.65 (1.38–1.97)</b>
		Yes	<b>160 (22.5%)</b>	<b>369 (52.0%)</b>	<b>181 (25.5%)</b>		
Take this job again (very likely – very unlikely)	1834	No	<b>368 (32.7%)</b>	<b>437 (38.9%)</b>	<b>231 (20.6%)</b>	<b>88 (7.8%)</b>	<b>1.63 (1.38–1.94)</b>
		Yes	<b>153 (21.5%)</b>	<b>284 (40.0%)</b>	<b>198 (27.9%)</b>	<b>75 (10.6%)</b>	
Mentally exhausted (never – always)	1834	No	269 (23.9%)	561 (49.9%)	244 (21.7%)	50 (4.4%)	0.87 (0.73–1.04)
		Yes	205 (28.9%)	321 (45.2%)	153 (21.5%)	31 (4.4%)	
Physically exhausted (never – always)	1834	No	124 (11.0%)	540 (48.0%)	350 (31.1%)	110 (9.8%)	0.98 (0.82–1.17)
		Yes	88 (12.4%)	333 (46.9%)	212 (29.9%)	77 (10.8%)	
Get along with supervisor (almost always – hardly ever)	1834	No	<b>768 (68.3%)</b>	<b>308 (27.4%)</b>	<b>48 (4.3%)</b>		<b>1.36 (1.12–1.66)</b>
		Yes	<b>439 (61.8%)</b>	<b>219 (30.8%)</b>	<b>52 (7.3%)</b>		

Note: bold – statistically significant at  $P = 0.05$ .

Table 4. Working overtime and psychosocial variables, frequency (proportion) and odds ratio (higher rating to lower rating).

Psychosocial variable (rating scale direction)	N	Working overtime	Psychosocial variable rating				OR (95% CI)
			1	2	3	4	
Employer cares about health and safety (strongly agree – strongly disagree)	1834	No	<b>326 (22.3%)</b>	<b>928 (63.6%)</b>	<b>150 (10.3%)</b>	<b>56 (3.8%)</b>	
		Yes	<b>124 (33.2%)</b>	<b>212 (56.7%)</b>	<b>26 (7.0%)</b>	<b>12 (3.2%)</b>	<b>0.61 (0.48–0.76)</b>
Depressed (never – always)	1834	No	404 (27.7%)	825 (56.5%)	210 (14.4%)	21 (1.4%)	
		Yes	101 (27.0%)	203 (54.3%)	59 (15.8%)	11 (2.9%)	1.12 (0.89–1.39)
General health (much better – much worse)	1834	No	204 (14.0%)	502 (34.4%)	597 (40.9%)	157 (10.8%)	
		Yes	59 (15.8%)	129 (34.5%)	146 (39.0%)	40 (10.7%)	0.92 (0.75–1.14)
Get along with co-workers (almost always – hardly ever)	1834	No	<b>728 (49.9%)</b>	<b>613 (42.0%)</b>	<b>119 (8.2%)</b>		
		Yes	<b>219 (58.6%)</b>	<b>132 (35.3%)</b>	<b>23 (6.1%)</b>		<b>0.71 (0.57–0.89)</b>
Recommend job to others (strongly recommend – not recommend at all)	1834	No	<b>195 (13.4)</b>	<b>736 (50.4%)</b>	<b>337 (23.1%)</b>	<b>192 (13.2%)</b>	
		Yes	<b>83 (22.2%)</b>	<b>158 (42.2%)</b>	<b>98 (26.2%)</b>	<b>35 (9.4%)</b>	<b>0.77 (0.62–0.95)</b>
Satisfaction with job (satisfied – dissatisfied)	1834	No	413 (28.3%)	748 (51.2%)	299 (20.5%)		
		Yes	108 (28.9%)	193 (51.6%)	73 (19.5%)		0.96 (0.77–1.19)
Take this job again (very likely – very unlikely)	1834	No	416 (28.5%)	572 (39.2%)	334 (22.9%)	138 (9.5%)	
		Yes	105 (28.1%)	149 (39.8%)	95 (25.4%)	25 (6.7%)	0.98 (0.79–1.20)
Mentally exhausted (never – always)	1834	No	374 (25.6%)	692 (47.4%)	335 (22.9%)	59 (4.0%)	
		Yes	100 (26.7%)	190 (50.8%)	62 (16.6%)	22 (5.9%)	0.89 (0.72–1.10)
Physically exhausted (never – always)	1834	No	171 (11.7%)	701 (48.0%)	458 (31.4%)	130 (8.9%)	
		Yes	41 (11.0%)	172 (46.0%)	104 (27.8%)	57 (15.2%)	1.20 (0.98–1.49)
Get along with supervisor (almost always – hardly ever)	1834	No	950 (65.1%)	431 (29.5%)	79 (5.4%)		
		Yes	257 (68.7%)	96 (25.7%)	21 (5.6%)		0.86 (0.68–1.10)

Note: bold – statistically significant at  $P = 0.05$ .

Table 5. Having a second job and psychosocial variables, frequency (proportion) and odds ratio (higher rating to lower rating).

Psychosocial variable (rating scale direction)	N	Having a second job	Psychosocial variable rating				OR (95% CI)
			1	2	3	4	
Employer cares about health and safety (strongly agree – strongly disagree)	1415	No	295 (23.1%)	809 (63.3%)	132 (10.3%)	42 (3.3%)	
		Yes	30 (21.9%)	92 (67.2%)	9 (6.6%)	6 (4.4%)	0.97 (0.68–1.38)
Depressed (never – always)	1415	No	352 (27.5%)	722 (56.5%)	188 (14.7%)	16 (1.3%)	
		Yes	36 (26.3%)	78 (56.9%)	20 (14.6%)	3 (2.2%)	1.07 (0.76–1.51)
General health (much better – much worse)	1415	No	168 (13.1%)	443 (34.7%)	528 (41.3%)	139 (10.9%)	
		Yes	25 (18.2%)	45 (32.8%)	53 (38.7%)	14 (10.2%)	0.83 (0.60–1.15)
Get along with co-workers (almost always – hardly ever)	1415	No	<b>643 (50.3%)</b>	<b>533 (41.7%)</b>	<b>102 (8.0%)</b>		
		Yes	<b>82 (59.9%)</b>	<b>46 (33.6%)</b>	<b>9 (6.6%)</b>		<b>0.69 (0.49–0.98)</b>
Recommend job to others (strongly recommend – not recommend at all)	1415	No	160 (12.5%)	661 (51.7%)	289 (22.6%)	168 (13.1%)	
		Yes	27 (19.7%)	55 (40.1%)	40 (29.2%)	15 (10.9%)	0.93 (0.66–1.29)
Satisfaction with job (satisfied – dissatisfied)	1415	No	360 (28.2%)	672 (52.6%)	246 (19.2%)		
		Yes	41 (29.9%)	36 (26.3%)	60 (43.8%)		1.15 (0.82–1.60)
Take this job again (very likely – very unlikely)	1415	No	368 (28.8%)	492 (38.5%)	291 (22.8%)	127 (9.9%)	
		Yes	39 (28.5%)	53 (38.7%)	33 (24.1%)	12 (8.8%)	1.00 (0.72–1.37)
Mentally exhausted (never – always)	1415	No	318 (24.9%)	627 (49.1%)	279 (21.8%)	54 (4.2%)	
		Yes	38 (27.7%)	63 (46.0%)	33 (24.1%)	3 (2.2%)	0.92 (0.66–1.27)
Physically exhausted (never – always)	1415	No	144 (11.3%)	618 (48.4%)	402 (31.5%)	114 (8.9%)	
		Yes	16 (11.7%)	65 (47.4%)	46 (33.6%)	10 (7.3%)	0.98 (0.71–1.37)
Get along with supervisor (almost always – hardly ever)	1415	No	817 (63.9%)	384 (30.0%)	77 (6.0%)		
		Yes	87 (63.5%)	46 (33.6%)	4 (2.9%)		0.97 (0.68–1.40)

Note: bold – statistically significant at  $P = 0.05$ .

Table 6. Relationships between work pace type and psychosocial variables, frequency (proportion) and odds ratio (higher rating to lower rating).

Psychosocial variable (rating scale direction)	N	Work pace type	Psychosocial variable rating				OR (95% CI)
			1	2	3	4	
Employer cares about health and safety (strongly agree – strongly disagree)	1824	Machine	179 (21.0%)	551 (64.7%)	83 (9.8%)	38 (4.5%)	1.07 (0.90–1.27)
		Self	231 (26.4%)	530 (60.5%)	92 (10.5%)	23 (2.6%)	
Depressed (never – always)	1824	Piece	<b>37 (38.1%)</b>	<b>54 (55.7%)</b>	<b>1 (1.0%)</b>	<b>5 (5.2%)</b>	<b>0.60 (0.40–0.88)</b>
		Machine	245 (28.8%)	483 (56.8%)	108 (12.7%)	15 (1.8%)	0.85 (0.70–1.01)
General health (much better – much worse)	1824	Self	227 (25.9%)	495 (56.5%)	144 (16.4%)	10 (1.1%)	
		Piece	29 (29.9%)	46 (47.4%)	15 (15.5%)	7 (7.2%)	1.06 (0.71–1.60)
Get along with co-workers (almost always – hardly ever)	1824	Machine	113 (13.3%)	302 (35.5%)	345 (40.5%)	91 (10.7%)	0.99 (0.83–1.18)
		Self	125 (14.3%)	295 (33.7%)	359 (41.0%)	97 (11.1%)	
Recommend job to others (strongly recommend – not recommend at all)	1824	Piece	<b>380 (44.7%)</b>	<b>396 (46.5%)</b>	<b>75 (8.8%)</b>	<b>8 (8.2%)</b>	<b>0.64 (0.44–0.94)</b>
		Machine	493 (56.3%)	321 (36.6%)	62 (7.1%)		<b>1.55 (1.29–1.86)</b>
Satisfaction with job (satisfied – dissatisfied)	1824	Self	<b>70 (72.2%)</b>	<b>23 (23.7%)</b>	<b>4 (4.1%)</b>		<b>0.50 (0.31–0.79)</b>
		Machine	<b>92 (10.8%)</b>	<b>423 (49.7%)</b>	<b>224 (26.3%)</b>	<b>112 (13.2%)</b>	<b>1.32 (1.11–1.57)</b>
Take this job again (very likely – very unlikely)	1824	Self	150 (17.1%)	423 (48.3%)	197 (22.5%)	106 (12.1%)	
		Piece	<b>32 (33.0%)</b>	<b>47 (48.5%)</b>	<b>10 (10.3%)</b>	<b>8 (8.2%)</b>	<b>0.41 (0.28–0.61)</b>
Mentally exhausted (never – always)	1824	Machine	<b>210 (24.7%)</b>	<b>461 (54.2%)</b>	<b>180 (21.2%)</b>		<b>1.20 (1.00–1.44)</b>
		Self	269 (30.7%)	425 (48.5%)	182 (20.8%)		
Physically exhausted (never – always)	1824	Piece	<b>36 (37.1%)</b>	<b>54 (55.7%)</b>	<b>7 (7.2%)</b>		<b>0.60 (0.41–0.90)</b>
		Machine	<b>228 (26.8%)</b>	<b>338 (39.7%)</b>	<b>211 (24.8%)</b>	<b>74 (8.7%)</b>	<b>1.07 (0.90–1.27)</b>
Get along with supervisor (almost always – hardly ever)	1824	Self	252 (28.8%)	343 (39.2%)	200 (22.8%)	81 (9.2%)	
		Piece	<b>40 (41.2%)</b>	<b>35 (36.1%)</b>	<b>15 (15.5%)</b>	<b>7 (7.2%)</b>	<b>0.60 (0.40–0.88)</b>
Get along with supervisor (almost always – hardly ever)	1824	Machine	237 (27.8%)	397 (46.7%)	180 (21.2%)	37 (4.3%)	0.88 (0.73–1.04)
		Self	205 (23.4%)	439 (50.1%)	198 (22.6%)	34 (3.9%)	
Get along with supervisor (almost always – hardly ever)	1824	Piece	28 (28.9%)	42 (43.3%)	17 (17.5%)	10 (10.3%)	0.95 (0.65–1.41)
		Machine	89 (10.5%)	408 (47.9%)	261 (30.7%)	93 (10.9%)	1.23 (1.03–1.47)
Get along with supervisor (almost always – hardly ever)	1824	Self	114 (13.0%)	432 (49.3%)	264 (30.1%)	66 (7.5%)	
		Piece	<b>6 (6.2%)</b>	<b>30 (30.9%)</b>	<b>34 (35.1%)</b>	<b>27 (27.8%)</b>	<b>3.28 (2.22–4.84)</b>
Get along with supervisor (almost always – hardly ever)	1824	Machine	<b>579 (68.0%)</b>	<b>232 (27.3%)</b>	<b>40 (4.7%)</b>		<b>0.76 (0.62–0.92)</b>
		Self	541 (61.8%)	278 (31.7%)	57 (6.5%)		
Get along with supervisor (almost always – hardly ever)	1824	Piece	<b>80 (82.5%)</b>	<b>14 (14.4%)</b>	<b>3 (3.1%)</b>		<b>0.35 (0.20–0.59)</b>

Note: bold – statistically significant at  $P = 0.05$ .

Table 7. Relationships between work pace type and task level biomechanical exposures.

Biomechanical exposure	Work pace type	Number of subjects	Median	$P > \chi^2$	Pairwise comparison ( $P > \text{DSCF}$ )
Effort/min (all, task)	Machine (M)	1858	19.1	< 0.0001	<b>M:S (&lt;0.0001)</b> M:P (0.21) S:P (0.37)
	Self (S)	1708	17.1		
	Piece (P)	112	20.3		
Effort/min (Borg $\geq$ 2, task)	Machine (M)	1858	5.8	< 0.0001	<b>M:S (&lt;0.0001)</b> <b>M:P (&lt;0.0001)</b> <b>S:P (&lt;0.0001)</b>
	Self (S)	1708	2.6		
	Piece (P)	112	0.0		
DC (all, task)	Machine (M)	1858	66.1	< 0.0001	M:S (0.20) <b>M:P (&lt;0.0001)</b> <b>S:P (&lt;0.0001)</b>
	Self (S)	1708	63.7		
	Piece (P)	112	88.1		
DC (Borg $\geq$ 2, task)	Machine (M)	1858	19.0	< 0.0001	<b>M:S (&lt;0.0001)</b> <b>M:P (&lt;0.0001)</b> <b>S:P (&lt;0.0001)</b>
	Self (S)	1708	11.9		
	Piece (P)	112	0.0		
HAL (task)	Machine (M)	1858	4.0	< 0.0001	<b>M:S (&lt;0.0001)</b> <b>M:P (&lt;0.0001)</b> <b>S:P (&lt;0.0001)</b>
	Self (S)	1708	4.0		
	Piece (P)	112	7.0		
Peak force (task/analyst)	Machine (M)	1858	3.0	< 0.0001	<b>M:S (0.0003)</b> <b>M:P (&lt;0.0001)</b> <b>S:P (&lt;0.0001)</b>
	Self (S)	1708	3.0		
	Piece (P)	112	1.0		
Peak force (task/worker)	Machine (M)	1040	3.0	< 0.0001	<b>M:S (&lt;0.0001)</b> M:P (0.99) S:P (0.50)
	Self (S)	983	4.0		
	Piece (P)	64	3.0		

Note: Median, bold – statistically significant at  $P = 0.05$ ; Kruskal–Wallis test; M, machine-paced; S, self-paced; P, piece rate; DC, Duty Cycle; HAL, Hand Activity Level.

disappeared. Jobs with overtime work had significantly lower peak forces compared to those without overtime work based on their Wilcoxon ranking score, though the median value was only 2.0 vs. 3.0 on the Borg scale. Jobs with overtime work usually had higher repetition (measured by either HAL and efforts per minute of typical forces, Table 2).

Those who had overtime jobs more likely strongly agreed that their ‘employers cared about their health and safety’ (Table 4, OR: 0.61). Many of them reported almost always ‘getting along with their co-workers’ (OR: 0.71) and would strongly ‘recommend their jobs to others’ (OR: 0.77). There was a likely relationship that those who had overtime work felt always ‘physically exhausted’ than those without overtime work (OR: 1.20), although this was not statistically significant (Table 4).

### Having second job

Having a second job did not seem to have any statistically significant association with any of the biomechanical measures (Table 2). It also did not show any statistically significant association with most of the psychosocial measures except that they were more likely to believe that they almost always ‘getting along with their co-workers’ (Table 5, OR: 0.69).

### Work pace

The relationships between work pace and psychosocial and biomechanical variables are shown in Tables 6 and 7. Work pace type had statistically significant associations with all biomechanical measures at the task level ( $P < 0.0001$ , Table 7). Machine-paced tasks had higher Wilcoxon mean score of repetition of all exertions compared to that of self-paced tasks ( $P < 0.0001$ ). Piece rate tasks had a lower Wilcoxon score for forceful repetition compared to that of either machine-paced or self-paced ( $P < 0.0001$ ). Piece rate tasks also had longer durations of exertion (all exertions) based on Wilcoxon score compared to that of either machine-paced or self-paced tasks ( $P < 0.0001$ ). However, such relationships were reversed when the variable of forceful exertions were used. In this situation, the machine-paced tasks had the highest Wilcoxon score, followed by the self-paced and the piece rate tasks had the lowest score ( $P < 0.0001$ ). Regarding HAL rating, tasks with piece rate had the highest Wilcoxon score, followed by machine-paced, and self-paced tasks had the lowest Wilcoxon score ( $P < 0.0001$ ). However, while the median HAL value of the piece rate group was much higher (7.0 on the HAL verbal scale), the median HAL values of the machine-paced and self-paced were all the same (4.0 on the HAL verbal scale).

Table 8. Relationships between work pace type and job level biomechanical exposures.

Biomechanical exposure	Work pace type	Number of subjects	Median	$P > \chi^2$	Pairwise comparison ( $P > \text{DSCF}$ )
SI (typical)	Machine (M)	855	3.4	<b>&lt; 0.0001</b>	<b>M:S (&lt;0.0001)</b>
	Self (S)	919	2.6		<b>M:P (0.0010)</b>
	Piece (P)	97	6.8		<b>S:P (&lt;0.0001)</b>
SI (TWA)	Machine (M)	855	3.0	<b>&lt; 0.0001</b>	<b>M:S (&lt;0.0001)</b>
	Self (S)	919	2.3		<b>M:P (&lt;0.0001)</b>
	Piece (P)	97	6.8		<b>S:P (&lt;0.0001)</b>
SI (peak)	Machine (M)	855	4.5	<b>&lt; 0.0001</b>	<b>M:S (&lt;0.0001)</b>
	Self (S)	919	3.0		<b>M:P (0.0042)</b>
	Piece (P)	97	6.8		<b>S:P (&lt;0.0001)</b>
TLV for HAL (TWA)	Machine (M)	855	0.40	<b>&lt; 0.0001</b>	<b>M:S (&lt;0.0001)</b>
	Self (S)	919	0.35		M:P (0.29)
	Piece (P)	97	0.33		S:P (0.55)
TLV for HAL (peak)	Machine (M)	855	0.50	<b>&lt; 0.0001</b>	<b>M:S (&lt;0.0001)</b>
	Self (S)	919	0.40		<b>M:P (0.0003)</b>
	Piece (P)	97	0.33		S:P (0.83)
TLV for HAL (typical)	Machine (M)	855	0.50	<b>&lt; 0.0001</b>	<b>M:S (&lt;0.0001)</b>
	Self (S)	919	0.40		<b>M:P (0.0009)</b>
	Piece (P)	97	0.33		S:P (0.96)

Note: Median, bold – statistically significant at  $P = 0.05$ ; Kruskal–Wallis test; M, machine-paced; S, self-paced; P, piece rate; SI, Strain Index; HAL, Hand Activity Level; TWA, Time Weighted Average.

Machine-paced tasks had analyst estimated peak forces ('peak force (task/analyst)'), with the highest Wilcoxon score, followed by self-paced, and piece rate tasks had the lowest Wilcoxon score ( $P < 0.0001$ ), although the median values were not much different specially between machine-based and self-paced (both were 3.0 in terms of Borg scales, Table 7). When the hand forces were self-reported, the machine-paced group had lower Wilcoxon mean score compared to the self-paced group ( $P < 0.0001$ ). Again, the difference in median values between the two groups was not large (3.0 vs. 4.0 measured by the Borg scale). No statistically significant relationships were found between piece rate tasks and the other two work pace types when the forces were self-reported.

At the job level, work pace had statistically significant associations with job biomechanical stressors evaluated by either the Strain index or the ACGIH TLV for HAL (Table 8). However, the relationships were inconsistent between the two methods of biomechanical evaluations. With the Strain Index method (no matter which method was used to compute the index), piece rate jobs had the highest Wilcoxon mean scores (hence higher risk), followed by machine-paced jobs, and the self-paced jobs had the lowest Wilcoxon scores ( $P < 0.0001$ ). With the ACGIH TLV for HAL evaluation method, machine-paced generally had higher Wilcoxon mean scores (hence higher risk) than self-paced, and the piece rate except when the time-weighted-averaging method was used (Table 8).

Work pace also had several statistically significant impacts on psychosocial variables as well (Table 6). More workers with piece rate jobs strongly agreed that their 'employers cared about their health and safety' compared to self-paced (OR: 0.60). However, fewer workers with machine-paced jobs had such beliefs (OR: 1.07). More workers with piece rate jobs also felt that they 'always get along with their supervisors or co-workers' compared to self-paced (OR: 0.35/0.50), but fewer workers with machine-paced jobs felt that way. Workers with machine-paced jobs felt that they could 'hardly ever get along with their-co-workers' (OR: 1.55), but could 'almost always get along with their supervisors' compared to self-paced (OR: 0.76).

More workers with piece rate jobs reported being satisfied with their jobs and might strongly 'recommend their jobs to others' compared to self-paced (OR: 0.41), but fewer workers in the machine-paced jobs felt satisfied and were more likely not to 'recommend their jobs to others' compared to the self-paced (OR: 1.55). Both piece rate and machine-paced groups reported being always 'physically exhausted' than the self-paced group (OR: 3.28 and 1.23 respectively). The piece rate group was also more likely to report 'depressed' than the self-paced group (OR: 1.06).

## Discussions

This large, pooled study of jobs at many diverse US workplaces found that several work organisational factors had significant associations with both biomechanical stressors and psychosocial factors. Job rotation, overtime work and the type of work pace had strong associations with the biomechanical and psychosocial measures.

### **Job rotation**

Job rotation has long been implemented as an administrative ergonomics intervention to attempt to reduce job biomechanical stressors and improve psychosocial factors through varying work tasks where one or more tasks are considered to have high risk of MSDs (Jonsson 1988; NIOSH 1997; Westgaard and Winkel 2011). While engineering interventions are widely considered preferable to administrative interventions, many companies utilise job rotation as a first choice as it is low cost, easy to implement and there are not infrequent difficulties to invent engineering interventions. Our study showed that almost 40% of this study's workers had job rotations. This figure is comparable to several other studies. Jorgensen et al. (2005) found that 42.7% companies from Midwest US manufacturing companies used job rotation. Another report found that about 23% workers whose jobs involving lifting and lowering tasks also had rotated jobs (Dempsey 2002).

The effectiveness of the job rotation strategy on preventing WMSDs lacks adequate scientific data. According to a recent review on job rotation, Leider et al. (2015) concluded that there is currently inconsistent evidence for the health benefits of job rotation on WMSDs. One of the arguments that job rotation improves musculoskeletal health is that it introduces task variation (Mathiassen 2006). However, a recent review of task variation found a lack of evidence that there are sufficient task variations among tasks in most workplaces that can be used to implement meaning job rotations to improve musculoskeletal health (Luger et al. 2014). Our results (Tables 2 and 3) showed that those workers who had job rotations still had both higher job biomechanical stressors and higher levels of several individual job physical factors compared to those who had only one job task (without job rotations). They were also in general less likely to be satisfied with their jobs. These findings appear similar to the findings of the two reviews cited above: (1) job rotation did not reduce biomechanical stressors in workplaces, and (2) the lack of sufficient task variations among jobs may be part of the reasons that currently practiced job rotation in workplaces is not successful in improving musculoskeletal health. Additionally, these data raise the possibility that job rotation that currently practiced in many US workplaces may not meaningfully improve psychosocial factors such as job satisfaction (Table 3).

This study is a cross-sectional study. We did not study the types of job rotations, but only the exploratory analyses on relationships between job rotation and biomechanical/psychosocial variables of the whole study population. It may be interesting to have further detailed study on the biomechanical exposures of tasks in job rotations. Even without detailed analysis results, our observations during worksite data collection confirm that many workplaces did use job rotation as an intervention strategy, yet the tasks that workers rotated between had very similar exposures (e.g. from one assembly to another assembly task).

### **Overtime work**

A growing body of evidence suggests that long working hours adversely affect the health and well-being of workers with reported associations of hypertension, cardiovascular disease, fatigue, stress, depression, MSD, chronic infections, diabetes, general health complaints and all-cause mortality (Dembe et al. 2005). Responses to a survey from more than 10,000 American workers suggest that job schedules with long working hours have greater associated risks not merely because they are concentrated in inherently hazardous industries or occupations, or because people working long hours spend more total time at risk for a work injury (Dembe et al. 2005). Our results showed that those with overtime work had higher job biomechanical exposure levels as measured by the Strain Index method (Table 2).

Some unexpected results also surfaced in this study. Those who worked overtime more likely 'strongly agreed that their employers cared about their health and safety' and they also reported 'almost always getting along with their co-workers and would strongly recommend their jobs to others' (Table 4) despite that their jobs had higher biomechanical exposures (Table 2). One speculation about the results might be that workers on those jobs may appreciate the financial rewards from working overtime, and working overtime is in many cases a privilege that requires management approval and often is assigned based on job seniority. This speculation is based on our experience working in many US workplaces where working overtime is often considered a privilege. Since jobs with overtime usually had lower peak forces compared to those without overtime (Table 2), those workers might have over-estimated their capacity. Jobs with overtime actually had higher repetition and high hand activity levels (HAL) (Table 2). These factors may make the jobs with overtime having greater musculoskeletal risk compared to jobs without overtime.

While the Strain Index method showed that jobs with overtime had higher biomechanical risks compared to those without overtime, the ACGIH TLV for HAL method was not able to provide similar conclusion. Possible explanation might be that the Strain Index had a 'duration per day' variable in its computation (Moore and Garg 1995), but the ACGIH TLV for HAL method considers any jobs with  $\geq 4$ h duration as having the same risk level when all other factors are constant (ACGIH 2001). The Strain Index also includes interactions of job physical factors through multiplication of risk factor multipliers, potentially providing higher fidelity (Moore and Garg 1995; Garg, Kapellusch,

et al. 2012). These differences may make the Strain Index more sensitive, and be also more useful where overtime work is studied.

### *Having second job*

A recent study of the US National Health Interview Survey (NHIS) to estimate the rate of workers with multiple jobs showed that approximately 8.4% of those employed reported working more than one job (Marucci-Wellman et al. 2014). Result of our study reporting 7.5% having second jobs is comparable. The NHIS study also found that working multiple jobs is associated with an increased risk of injury, both at work and not at work. However, our results could not demonstrate any statistically significant association of having second jobs on either the biomechanical or psychosocial variables except that those having second jobs were more likely to believe that they almost always 'getting along with their co-workers' (Tables 2 and 5). Health outcome measures (injuries) were not included in the present analyses. It is our plan to look at the relationships between the work organisation variables including the variable of having second job and health outcome variables (prevalence of carpal tunnel syndrome and epicondylitis cases) in future further analyses.

One of the limitations of this study is that there were significant missing data on the variable of 'having second job'. Among the total 1834 participants in the study, 419 (23%) participants had missing information on this work organisational variable. Although there is not a systematic bias in these missing data, this might partially contribute to the non-significant findings on relationships between this work organisational variable and the biomechanical and psychosocial variables largely due under-powering. Additional limitations are particularly related to the cross-sectional study design including potential for recall bias and lack of temporality. Additionally, these data cannot demonstrate temporality and therefore are only able to describe associations, not causal relationships.

### *Work pace*

Studies on work pace have produced inconsistent results in the literature. A systematic review to assess whether occupational and non-occupational psychosocial factors are risk factors for the occurrence of back pain found insufficient evidence for an effect of a high work pace (Hoogendoorn et al. 2000). However, a recent review of studies in lean manufacturing environments in the past 20 years found increased musculoskeletal symptoms were related to increases of work pace (Koukoulaki 2014). Our study also showed that with different job evaluation methods, the conclusions might be different. While piece rate jobs always had the highest biomechanical exposure levels when they were evaluated by the Strain Index method (Table 8), machine-paced jobs had the highest biomechanical exposure levels when they were evaluated by the ACGIH TLV for HAL method. This difference might be due to the fact that the Strain Index considered the overtime work (> 8 h/day) while the ACGIH TLV for HAL method assumes that the risk level is the same when exposure duration is equal to or greater than 4 h/day as mentioned before. More piece rate workers worked overtime that was shown in our correlation analysis. Therefore, the Strain Index was able to demonstrate the increased risk due to longer work duration.

Piece rate jobs may have higher musculoskeletal risks. Workers at those jobs also often felt 'physically exhausted', yet piece rate workers seem generally more satisfied with their jobs and that they strongly agreed that their 'employers cared about their health and safety', they always 'got along with their supervisors or co-workers', reported being 'satisfied with their jobs', and would very likely 'take this job again' and strongly 'recommend their jobs to others' (Table 8).

The influence of work pace on workers' health may be quite complex. Bosch et al. (2011) conducted a study evaluating relationships between work pace characterised by a detailed predetermined time system (or MTM) and measures of workload, motor variability and fatigue in a light cyclic assembly setting. They concluded that an increased work pace within the studied range does not have any substantial adverse effects on acute motor performance and fatigue. Another study compared two pacing conditions: (1) a relatively fast pacing controlled by a predetermined time system at a pace of 10% faster than normal (or MTM 110) and (2) a self-paced condition (Dempsey et al. 2010). The authors found that while the average cycle times for both conditions remained fairly constant, the self-paced condition produced significantly higher number of assemblies than the controlled condition by reducing the idle time during the assemblies.

The impact of work pace on biomechanical stressors may also be related to the way that the work pace is controlled. Petit et al. (2014) found that work pace dependent on customers was associated with increased neck disorders in men with an odds ratio of 1.42 (95% confidence interval (CI): 1.10–1.83), and work pace dependent on quantified targets was associated with increased neck disorders in women with an odds ratio of 1.37 (95% CI: 1.05–1.79) among a cohort of 3710 workers in a representative working population. Our study characterised work pace by machine-paced, self-paced and piece rate. We found that machine-paced jobs usually had higher hand exertion repetitions of all exertions (Table 7). However,

piece rate jobs had higher repetitions of forceful exertions. Piece rate jobs generally had lower force requirements than machine-paced and self-paced.

Further research is needed on the relationships between work pace and biomechanical and psychosocial factors. More detailed operational variable definitions of the work pace may be necessary so that one can better understand how the work pace influence biomechanical exposures. Understanding of the nature of task within different work pace categories may also be of interest to understand their psychosocial efforts on the workers.

This study suggests that the relationships between work organisational factors, job biomechanical stressors and psychosocial factors are highly complicated. In general, work organisation variables had strong associations with many biomechanical and psychosocial variables. Further research is needed in all of these aspects. This study is of a cross-sectional nature. Longitudinal data are particularly needed to confirm effects that are not merely associative, but rather may potentially be causal.

### Disclosure statement

No potential conflict of interest was reported by the authors.

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