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ARTICLE



## Interaction between physical demands and job strain on musculoskeletal symptoms and work performance

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### ABSTRACT

This study investigated the interaction between physical demands and job strain on musculoskeletal symptoms in upper extremities (MSUE) and work performance. Two years of prospective data were analysed from 713 full-time workers from twelve manufacturing and healthcare facilities in Washington in the United States. Physical exposure was measured by the Strain Index and Threshold Limit Value for hand activity, giving rise to safe, action, and hazardous physical demand groups. Job strain was calculated as the ratio of psychological job demands to job control. Multilevel modelling analysis showed that job strain affected MSUE and limited work performance less in the high physical demand group than the safe group because the protective effect of job control was smaller in these groups. Findings may suggest that high physical demand jobs are structured such that workers have low job control or high physical demand groups experience job strain not adequately captured by psychosocial variables.

**Practitioner Summary:** The effects of job strain and job control on musculoskeletal symptoms in upper extremities and work performance were smaller among workers with higher physical demands. This could imply that high physical demand jobs limit job control or psychosocial variables may not adequately capture job strain among high physical demand groups.

**Abbreviations:** ACGIH: American Conference of Governmental Industrial Hygienists; AL: action limit; DASH: disabilities of the arm, shoulder, and hand questionnaire; HA: hand activity; JCQ: job content questionnaire; JDC: job demand-control model; MSDs: musculoskeletal disorders; MSUE: musculoskeletal symptoms in upper extremities; QuickDASH: a short version of the disabilities of the arm, shoulder, and hand questionnaire; SHARP: safety and health assessment and research for prevention; SI: strain index; TLV: threshold limit value; WMSDs: work-related musculoskeletal disorders

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Interaction; musculoskeletal disorder; work disability; occupational stress; job control; ergonomics

## Introduction

Musculoskeletal disorders (MSDs) are major occupational injuries and illnesses resulting in lost work productivity, sick leave, and early exit from work (World Health Organisation 2021). Work-related musculoskeletal disorders (WMSDs) are characterised by conditions in which a) the work environment or work tasks contributed significantly to the condition; and/or b) a pre-existing condition was made worse or persisted longer due to work (Bernard et al. 1997). The U.S. Bureau of Labor Statistics defines a WMSD case as when the musculoskeletal injury or illness results from a work-related event or exposure involving a bodily reaction

(e.g. bending, climbing, crawling, reaching, and twisting), overexertion, or repetitive motion. This definition does not include traumatic injuries caused by slips, trips, falls, or similar incidents. In 2019, among private industry workers in the U.S., WMSDs from overexertion and bodily reaction occurred at a rate of 26.1 cases per 10,000 full-time workers and accounted for 31% of days-away-from-work cases (U.S. Bureau of Labor Statistics 2021). In addition, the Washington State Department of Labour and Industries (2021) reported healthcare and the manufacturing work settings were at high risk for WMSDs involving days away from work in private industries in 2019.

Physical job factors (e.g. work posture, force exertion, and repetition) and psychosocial job factors (e.g. high psychological job demands, low job control, and high job strain) have been considered to be two major risk factors of WMSDs in previous studies (Bernard et al. 1997; Burton et al. 2008; Da Costa and Vieira 2010; National Research Council and Institute of Medicine 2001). While the relevance of each physical job factor on MSDs was supported by laboratory studies, the psychosocial job factors have been based on work stress theories. One of the most influential theoretical frameworks in work stress is the Job Demand-Control model (JDC; Karasek 1979; Karasek and Theorell 1990), which focussed on two dimensions from the work environment, job demands and job control. The JDC model conceptualised job demands as psychological job demands, which refer to how hard the work is including workload and time pressure. Job control refers to the ability to control work activities, including the ability to use skills on the job (skill discretion) and the decision-making authority available to the workers (decision authority). The JDC model purports that the risk to physical and mental health from stress occurs to workers when facing high job demands combined with low job control, which refers to job strain. This idea is based on the premise that job control buffers the effect of job demands on job strain. In empirical research, high psychological job demands, low job control, and high job strain have been consistently significant psychosocial risk factors on MSDs (Bernard et al. 1997; Burton et al. 2008; Da Costa and Vieira 2010; National Research Council and Institute of Medicine 2001).

Studies have indicated that physical and psychosocial hazards have a common mechanism that increases and sustains stress-induced muscle tension and the lack of muscle rest (Kerr et al. 2001; Lundberg 2002; Visser et al. 2004); the combined risk of high physical and psychosocial hazards could be greater than the sum of these two hazards, due to their interaction. This also indicates that job control may be able to modify the level of physical demands. For example, it may do so by allowing control over the organisation of physical work in a way which can provide sufficient recovery and rest, or by allowing new ways to utilise one's skills to do the work, subsequently reducing the risk of MSDs. A preponderance of studies have supported that an excess risk of WMSDs is attributable to the interactions between physical and psychosocial factors. For example, several cross-sectional studies have shown that workers exposed to both high physical and high psychosocial factors are more likely to

have lower back pain (Devereux, Buckle, and Vlachonikolis 1999), neck and upper-limb disorders (Devereux, Vlachonikolis, and Buckle 2002; Widanarko et al. 2015b), and reduced activities and increased absenteeism (Widanarko et al. 2015a). Additionally, cohort studies have shown their interaction effects on new episodes of neck and upper extremity pain among both white- and blue-collar workers (Devereux et al. 2004), on quality of life among gas and electrical workers (Sabbath et al. 2013), on the presence of neck and shoulder pain among coal miners (Widanarko et al. 2015a), on the sickness absence among care assistants (Helgesson et al. 2020), and on the disability pension among care assistants and non-health care workers (Gustafsson et al. 2020). Vandergrift et al. (2012) found a three-way interaction among physical factors, job control, and psychological job demands in incidents of lower back pain among automobile manufacturing workers. Specifically, the relationship between low back pain and psychological job demands depended on the level of job control among the high physical demand group but not among the low physical demand group. On the contrary, a few studies did not find interaction effects (Harris-Adamson et al. 2016; Pereira 2009; Prakash et al. 2017).

In examining interaction effects, all of the aforementioned studies except for a study by Harris-Adamson et al. (2016) measured physical factors through self-report, which is subject to information bias. Investigating the interaction between objectively measured physical demands and job strain may provide more valid evidence on MSDs. The purpose of this study is to examine the interactions between objectively measured physical demands and job strain on musculoskeletal symptoms in the upper extremities (MSUE) and the resulting limitations on work performance.

## Methods

### *Design and sample*

This study was a secondary analysis of data from a prospective cohort of full-time workers from nine manufacturing and three healthcare worksites in the state of Washington. After the parent study received approval from the Washington State Institutional Review Board, data was collected from willing participants by the Safety and Health Assessment and Research for Prevention (SHARP) program of the Washington State Department of Labour and Industries from 2001 to 2004. SHARP initially

contacted manufacturing and healthcare facilities across western Washington that have more than 200 full-time employees, assuming that larger companies were more likely to have an adequate sample size and a sufficient variability in physical exposures in each of the departments. At willing facilities, certified professional ergonomists from SHARP checked eligible departments based on rough walk-through assessments. To be included in the study, each department employed at least 30 employees and had to have jobs in at least three out of six physical exposure categories (two levels of hand force [high/low] by three levels of repetition [high/medium/low]) (ACGIH 2001). The study excluded employees working part-time or temporarily, operating mobile vehicles, such as forklift driving, or performing jobs with more than four tasks, due to practical reasons or resource constraints on collecting individual level physical exposures. In addition, the study excluded departments with routine patient contact in healthcare facilities because of the requirement to videotape physical job exposures. The original SHARP study investigating occupational factors for MSDs in the upper extremities involved (1) an individual physical factor assessment by ergonomists (baseline and at follow-up if there was a job change); (2) a health interview (health history and job history) by trained interviewers (baseline, one year later, two years later); and (3) a self-administered psychosocial questionnaire (baseline, one year later, two years later).

At baseline, 733 participants met the inclusion criteria, a majority of which (86.5%) worked in the manufacturing sector (electronics, medical or exercise equipment, windows, kitchen cabinets, wood mills). Due to an economic recession that resulted in layoffs and terminations, the sample size decreased to 467 one year after baseline and 377 two years after baseline. This study excluded those who had a sudden injury to an upper extremity within a year from each data collection time point ( $n=29$  at baseline,  $n=15$  one year later,  $n=10$  two years later) and participants whose data records regarding all psychosocial job factors were lost ( $n=35$  at baseline,  $n=24$  one year later,  $n=14$  two years later). Overall, for the present study, analysis was based on 1450 observations ( $n=669$  at baseline,  $n=428$  one year later,  $n=353$  two years later) from a total of 713 individuals (Figure 1).

## Measurement

### Physical job factors

Physical exposures were measured at the individual task level at the time of enrolment in the original

SHARP study and measured again if the participant reported a job change. The information of job change was collected in 4-month intervals during the study period. During the site visit, the percentage of time spent on each job task was gathered in interviews with participants or their supervisors. Individual level exposures were determined by the analysis of video recording of participants completing job tasks from two angles for synchronised views and analysed in a laboratory using the Multimedia Video Task Analysis software (Yen and Radwin 1995) to calculate duty cycle and frequency of forceful exertions. All video analyses were conducted by certified professional ergonomists blinded to workers' health status to minimise bias. Further details about the data collection, processing, and analysis have been reported elsewhere (Bao, Howard, et al. 2006; Bao, Spielholz, et al. 2006). Strain Index and Threshold Limit Value were each respectively used to estimate composite physical demands, which are two widely used ergonomic risk assessment tools for upper extremities in both practice and research (Garg et al. 2012). Since there is no gold standard to determine a composite physical demand on upper extremities, comparing the results measured by Strain Index and Threshold Limit Value may provide reliable results.

**Strain index (SI).** SI (Moore and Garg 1995) is a distal upper extremity physical exposure assessment, which is based on the product of the multipliers of six domains. Each domain has five ordinal ratings, but their respective multipliers are weighted differently. Domain multipliers ranged from: 1–13 in intensity of exertion, 0.5–3 in duration of exertion per cycle, 0.5–3 in efforts per minute, 1–3 in wrist posture, 1–2 in speed of exertion, and 0.25–1.5 in duration of task per day. To account for those performing multiple tasks, a time-weighted average for each domain was used for calculating the SI (Bao et al. 2009). A higher SI indicated strenuous physical exposure. Participants were categorised into three groups based on SI scores: Safe ( $SI \leq 3$ ), Action ( $3 < SI \leq 7$ ), and Hazardous ( $SI > 7$ ).

### Threshold limit value (TLV) for hand activity (HA).

The American Conference of Governmental Industrial Hygienists (ACGIH) developed a TLV for HA in 2001 and revised the equation in 2018 to conform to epidemiological studies (ACGIH 2019). Based on the HA level, corresponding normalised peak hand force TLV and the action limit (AL) were calculated. The measured peak forces of the workers were compared to the calculated normalised peak hand force thresholds

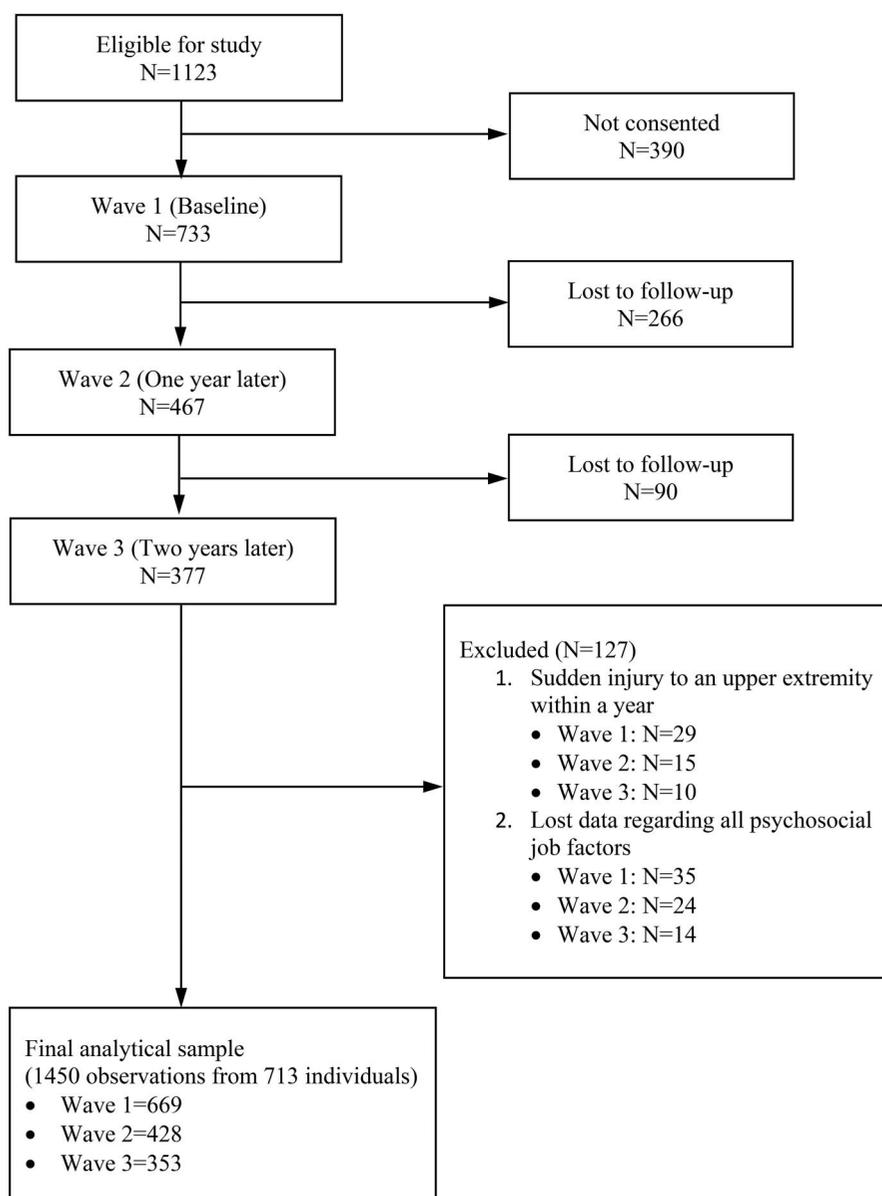


Figure 1. Flow diagram of study participants in this cohort study.

of TLV and AL and were categorised into the Safe (under the AL), Action (between AL and TLV), or Hazardous (above TLV) groups.

### Job strain

A widely used questionnaire to assess work stress is Job Content Questionnaire (JCQ; Karasek and Theorell 1990). In this study, an adapted version of the JCQ was used to assess psychological job demands through five items (working fast, working hard, no excessive work, enough time, hectic) and job control through nine items (learning new things, engaging in repetitive work, being creative, having a high level of skill, variety, receiving training, having

little freedom to decide, a lot to say, taking a break) (Silverstein et al. 2006). A revised item, 'hectic', replaced the 'conflicting demands' item in the psychological job demands scale. The items 'received training' and 'taking a break' replaced 'develop ability' and 'allow decision' in the job control scale. Each response was recorded as a 4-point Likert scale (Strongly Disagree-1, Disagree-2, Agree-3, and Strongly Agree-4). The total score ranged from 12 to 48 for psychological job demands and from 24 to 96 for job control.

Various formulations of job strain, such as quadrant, quotient, subtraction, and logarithm have been used in health studies. The most widely used formulation of

job strain is a quadrant term which classifies individuals as experiencing high job strain when they report above median scores for psychological job demands and below median scores for job control. However, the quadrant term has shown the lowest accuracy in predicting health outcomes compared to other formulations of job strain (the subtraction, logarithm, and quotient approaches) (Courvoisier and Perneger 2010). Therefore, a job strain quotient term was chosen for this current study because this approach is the second-most widely used one in research and it provides better accuracy than the quadrant term. The job strain quotient term created a continuous job strain measure, which was calculated by doubling psychological job demands and dividing by job control (Landsbergis et al. 1994, 2015). The job strain ranged from 0.25 to 4. A score more than 1 indicates job strain.

#### *MSUE and limited work performance*

MSUE and work performance were measured by the 11-item QuickDASH (a short version of the Disabilities of the Arm, Shoulder and Hand questionnaire; DASH) and its optional four-item work module, respectively (Kennedy CA, Beaton DE, Solway S, McConnell S, & Bombardier C., 2011). DASH was developed to evaluate symptom and functional status for patients with MSUE (Beaton et al. 2001). The short version of DASH, QuickDASH, has shown good reliability and validity (Beaton et al. 2005), as a good screening tool among workers with MSDs in upper extremities (Stover et al. 2007), and was shown to be sensitive to the occurrence or recovery of MSUE (Fan, Smith, and Silverstein 2011). Also, the work module showed high sensitivity for detecting work limitation (Gardner et al. 2016).

Participants who reported experiencing MSUE at least three times or who had pain lasting a week or longer in the prior 12 months were asked to complete the QuickDASH and its work module; otherwise they were treated as symptom-free and healthy. The QuickDASH asked participants to rate their ability to perform different daily activities and the severity of their MSUE in the last week. The work module asked them to rate their ability to perform work tasks in the last week. The specific questions asked about the degree of difficulty in using the usual technique for work, working with pain in the upper extremities, maintaining the quality of work, and completing work in the usual amount of time. Each item was rated on a five-point Likert scale (no difficulty-1, mild difficulty-2, moderate difficulty-3, severe difficulty-4, unable-5). The global scores [(the sum of scores/ the number of

items]  $-1 \times 25$ ) ranged from 0 to 100, with higher scores reflecting more severe MSUE and limited work performance.

#### *Confounders*

*Job security.* Two items from the modified version of JCQ (Silverstein et al. 2006) asked participants to rate the following: 'I have job security at my job' and 'I am likely to be laid off at my job'; the responses options were strongly disagree-1, disagree-2, agree-3, strongly agree-4.

*Co-worker support.* Work Apgar (Bigos et al. 1991) was used to assess level of support from co-workers. Four of the five original version questions were used to ask participants whether they could 'turn to a fellow worker for help', 'talk about things and share problems', 'accept and support others', and if co-workers 'responded to [their] emotions'. Responses were rated on a three-point Likert scale, ranging from hardly ever-1, some of the time-2, almost always-3, with higher scores indicating higher co-worker support.

*Personal factors.* Demographic information (age, gender, ethnicity, educational level, years employed in current job, and smoking status), status of comorbidities (prior diagnosis of thyroid disease, diabetes mellitus, and rheumatoid arthritis), and prior diagnosis of MSDs in upper extremities (carpal tunnel syndrome, thoracic outlet syndrome, hand/wrist tendinitis, epicondylitis, trigger finger, and rotator cuff syndrome) were collected via questionnaire. Types of comorbidities were chosen based on the previous literature that may act as a confounder on MSDs (Cakir et al. 2003; Nahin 2015; Roquelaure et al. 2009; Shafer et al. 2020)

#### *Data analysis*

Descriptive statistics were used to characterise the study sample at baseline, one year later, and two years later. Item non-responses for the psychosocial job questionnaires (psychological job demands [ $n=52$ ], job control [ $n=41$ ], job security [ $n=43$ ], co-worker support [ $n=58$ ]) were treated with multiple imputation using predictive mean matching. This imputation was done using the *MICE* package (van Buuren and Groothuis-Oudshoorn 2011) in R software. Later, a total summary score for each scale was computed using observed and imputed data.

Multilevel linear regression was used to analyse a data structure where observations (level 1) were

nested within a worker (level 2) in a company (level 3). The inclusion of company level of the data led to better fit via a likelihood ratio test comparing a null model and random intercept model on MSUE ( $p < .001$ ) and limited work performance ( $p = .007$ ). Confounders were personal factors (gender, age, race/ethnicity, education, smoking status, having any comorbid medical condition, and prior diagnosis of MSDs in upper extremities), occupational characteristics (years in current company, job security [high or low using a median] and co-worker support [high or low using a median]), and survey wave (a categorical term). To identify a parsimonious model, confounders that did not provide significant impact on the model fit according to likelihood ratio tests ( $p < .05$ ) were not included in the final model.

Two models were constructed, a main effects model of physical demands and job strain (Equation 1) and an interaction model that added the interaction term of physical demands and job strain to the main effects model (Equation 2). Since these two models were nested, likelihood ratio tests were carried out to examine the effect of the interaction between physical demands and job strain on the outcomes within random intercept multilevel models using a threshold of  $p < .05$ . Estimates were calculated from the fitted models along with 95% bootstrapped confidence intervals.

- Main effects and interaction models

$$y_{tij} = \beta_{0ij} + \beta_1 JS_{tij} + \beta_2 AG_{tij} + \beta_3 HG_{tij} + \alpha_1 C_{tij} + \dots + \alpha_n C_{tij} + \varepsilon_{tij} \quad (1)$$

$$y_{tij} = \beta_{0ij} + \beta_1 JS_{tij} + \beta_2 AG_{tij} + \beta_3 HG_{tij} + \beta_4 AG * JS_{tij} + \beta_5 HG * JS_{tij} + \alpha_1 C_{tij} + \dots + \alpha_n C_{tij} + \varepsilon_{tij} \quad (2)$$

(Where  $t$  refers to time [level 1],  $i$  refers to person [level 2],  $j$  refers to company [level 3],  $JS$  refers to job strain,  $AG$  refers to the action group,  $HG$  refers to the hazardous group,  $C$  refers to confounders,  $\varepsilon_{tij}$  refers to the error term of the level 1 intercept)

An interaction between physical demands and job strain would be indicated by interaction coefficients ( $\beta_4$  or  $\beta_5$ ) different from zero. The  $\beta_4$  coefficient expresses the magnitude of the difference in mean outcome level (musculoskeletal symptoms or work performance) in the 'action' compared to the 'safe' physical demands group for a one-unit increase in job strain. Similarly, the  $\beta_5$  coefficient expresses the magnitude of the difference in mean outcome level in the 'hazardous' compared to the 'safe' physical demands

group for a one-unit increase in job strain. Therefore, one unit increase in job strain in the Equation (2) is estimated to  $\beta_1$  higher outcome in the safe group,  $\beta_1 + \beta_4$  in the action group, and  $\beta_1 + \beta_5$  in the hazardous group, after adjusting the confounders. If a coefficient of the interaction was positive, it indicated that the combined effect of two exposures was greater than the sum of each exposure (synergistic interaction). On the other hand, if a coefficient of the interaction was negative, it indicated that the combined effect of two exposures was smaller than the sum of each exposure (antagonistic interaction). To display the impact of the interaction, the estimated effect of job strain among safe, action and hazardous group were provided graphically.

Additionally, to understand how psychological job demands and job control contribute to the interaction, a sensitivity analysis was conducted by treating job demands and job control as separate exposure variables. The effect of the interactions on MSUE and limited work performance were examined via likelihood ratio tests (1) between physical demands and psychological job demands, (2) between physical demands and job control, and (3) among physical demands, psychological job demands, and job control. This was done with the *lme4* package (Bates et al. 2015) in R software.

## Results

Demographic characteristics at each time point are presented in Table 1. Over the course of two years, 713 participants with 1450 observations ( $n = 669$  at baseline,  $n = 428$  one year later,  $n = 353$  two years later) were included in this present study. At baseline, the participants were 50% male, 60% white, 48% high school graduate, 57% reporting high co-worker support, and 68% reporting high job security. Of the participants, 9% had comorbidities, such as thyroid disease, diabetes mellitus, and rheumatoid arthritis, and 21% had a previous diagnosis of MSDs in upper extremities at baseline, such as carpal tunnel syndrome, thoracic outlet syndrome, hand/wrist tendinitis, epicondylitis, trigger finger, and rotator cuff syndrome. Regarding the SI, participants were equally distributed across the three different physical job risk categories, but slightly more participants were grouped in the hazardous group based on the TLV for HA. The means of MSUE and limited work performance were 8.17 ( $SD: 15.24$ , range: 0–77.27), and 11.67 ( $SD: 14.87$ , range: 0–100), respectively. Similar characteristics were observed in participants during the follow-up waves, except for

**Table 1.** Descriptive statistics of the participants, cohort study, 2001–2004.

		Baseline N = 669	Wave 2 N = 428	Wave 3 N = 353	p
Male	N (%)	348 (52)	214 (50)	164 (46)	.24
Age at baseline	M (SD)	39.4 (10.8)	40.1 (10.8)	41.2 (10.2)	.04
Race/Ethnicity					.94
White	N (%)	402 (60)	258 (60)	213 (60)	
Asian	N (%)	121 (18)	82 (19)	69 (20)	
Hispanic	N (%)	84 (13)	52 (12)	46 (13)	
Others	N (%)	62 (9)	36 (8)	25 (7)	
Education					.95
Less than high school	N (%)	113 (17)	69 (16)	51 (14)	
High school graduate	N (%)	494 (48)	205 (48)	167 (47)	
Some college	N (%)	175 (26)	110 (26)	99 (28)	
≥ Bachelor	N (%)	62 (9)	44 (10)	36 (10)	
Smoking status					.58
Non-smoker	N (%)	329 (49)	197 (46)	168 (48)	
Ex-smoker	N (%)	141 (21)	99 (23)	88 (25)	
Current smoker	N (%)	199 (30)	132 (31)	97 (27)	
Tenure at baseline (in years)	M (SD)	5.7 (6.9)	6.2 (7.2)	6.5 (7.6)	.21
Comorbidity <sup>a</sup>	N (%)	62 (9)	40 (9)	33 (9)	.99
MSDs in upper extremities at baseline <sup>b</sup>	N (%)	143 (21)	98 (23)	72 (21)	.69
Job strain	M (SD)	1.08 (0.27)	1.04 (0.23)	1.03 (0.23)	.003
High co-worker support (>7)	N (%)	380 (57)	235 (55)	191 (54)	.67
High job security (≥6)	N (%)	457 (68)	278 (65)	257 (73)	.06
Physical demands					
The Strain Index (SI)					.10
Safe (SI ≤ 3)	N (%)	225 (34)	155 (36)	149 (42)	
Action (3 < SI ≤ 7)	N (%)	200 (30)	128 (30)	96 (27)	
Hazardous (SI > 7)	N (%)	244 (36)	145 (34)	108 (31)	
Threshold limit value for hand activity					.59
Safe	N (%)	203 (30)	137 (32)	119 (34)	
Action	N (%)	181 (27)	126 (29)	97 (27)	
Hazardous	N (%)	285 (43)	165 (39)	137 (39)	
MSUE score <sup>c</sup>	M (SD)	11.67 (15.24)	10.74 (15.40)	10.96 (15.99)	.58
Limited work performance score <sup>d</sup>	M (SD)	8.17 (14.87)	6.94 (14.61)	6.91 (14.61)	.29

<sup>a</sup>Thyroid disease, diabetes mellitus, and rheumatoid arthritis.

<sup>b</sup>Musculoskeletal disorders in upper extremities including carpal tunnel syndrome, thoracic outlet syndrome, hand/wrist tendinitis, epicondylitis, trigger finger, and rotator cuff syndrome.

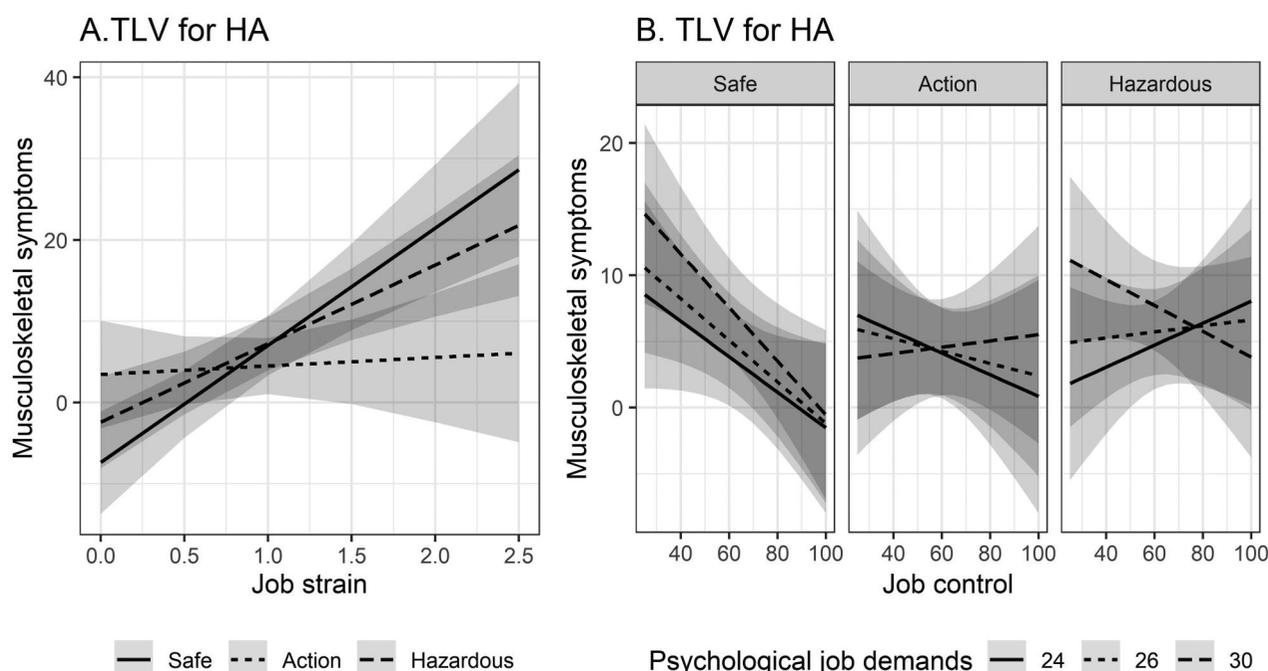
<sup>c</sup>MSUE: musculoskeletal symptoms in upper extremities. This was measured by the QuickDASH.

<sup>d</sup>This was measured by the QuickDASH work module.

**Table 2.** Results of multilevel linear regression for musculoskeletal symptoms in upper extremities (MSUE) score (range 0–100; based on QuickDASH;  $n = 1450$  observations across 713 individuals in 12 companies)<sup>a</sup>.

	Models using Strain Index		Models using TLV for HA	
	Model 1	Model 2	Model 3	Model 4
Fixed effects	Coeff (95% CI)	Coeff (95% CI)	Coeff (95% CI)	Coeff (95% CI)
Job strain	9.0 (5.7, 12.1)	10.7 (4.3, 16.0)	9.0 (5.3, 12.2)	14.5 (8.5, 20.9)
Physical demands				
Safe	–	–	–	–
Action	0.9 (–1.4, 2.9)	4.8 (–2.9, 12.1)	–1.0 (–3.4, 1.4)	10.7 (2.8, 18.8)
Hazardous	0.8 (–1.5, 2.9)	1.7 (–6.3, 8.8)	1.0 (–1.1, 3.0)	4.8 (–2.7, 11.9)
Safe × Job strain		–		–
Action × Job strain		–4.4 (–12.2, 4.1)		–13.3 (–22.0, –4.3)
Hazardous × Job strain		–1.1 (–8.6, 7.5)		–4.6 (–12.5, 3.5)
Random effects (intercepts)				
Between individuals in a company	99.5 (8.9, 10.7)	99.4 (9.0, 10.8)	99.1 (9.0, 10.6)	98.1 (9.0, 10.6)
Between companies	2.5 (0.0, 2.7)	2.5 (0.0, 2.6)	2.3 (0.0, 2.6)	2.3 (0.0, 2.6)
Residual	100.7 (9.5, 10.5)	100.6 (9.5, 10.5)	100.7 (9.5, 10.6)	100.2 (9.4, 10.5)
Loglikelihood	–5782.9	–5782.3	–5781.6	–5777.2

<sup>a</sup>TLV for HA: Threshold Limit Value for hand activity. All models were adjusted for gender, age, education, smoking status, and a previous musculoskeletal disorder in upper extremities (carpal tunnel syndrome, thoracic outlet syndrome, hand/wrist tendinitis, epicondylitis, trigger finger, and rotator cuff syndrome). To identify a parsimonious model, the confounders (race/ethnicity, comorbid medical condition, tenure, job security, co-worker support, and survey wave) that did not provide significant impact on model fit were deleted.



**Figure 2.** Estimated value of Musculoskeletal Symptoms in Upper Extremities (MSUE) score (A: Interaction between job strain and physical demands [Threshold Limit value for hand activity], B: Interaction among psychological job demands, job control, and physical demands [Threshold Limit value for hand activity]) [Shaded areas indicate 95% confidence intervals].

age and job strain. Age at baseline showed an increase from 39.4 years ( $SD: 10.8$ ) at baseline to 41.2 years ( $SD: 10.2$ ) two years later ( $p < .02$ ). On the other hand, job strain showed a significant decrease from 1.08 ( $SD: 0.27$ ) at the baseline to 1.03 ( $SD: 0.23$ ) at the last follow-up visit ( $p = .003$ ).

### The effect of physical demands and job strain on MSUE

Table 2 displays the regression models for the outcome MSUE, including estimations of the interaction between physical demands and job strain. For physical demands, SI (model 1 and model 2) and TLV for HA (model 3 and model 4) were analysed in separate models. Main effects are presented in models 1 and 3. Interaction effects are presented in models 2 and 4. Job strain showed a statistically significant effect on MSUE across all models after adjusting for gender, age, education level, smoking status, and previous MSDs in upper extremities at baseline. However, the effects of physical demands on MSUE were not statistically significant except in model 4.

Likelihood ratio tests were carried out to assess interactions between the SI and job strain (model 1 vs. model 2) and between TLV for HA and job strain (model 3 vs. model 4). A statistically significant interaction was observed between TLV for HA and job strain ( $p = .02$ ), though not between the SI and job strain ( $p$

$= .5$ ). Model 4 indicated a significant interaction between physical demands measured by TLV for HA and job strain only in the action group ( $B = -13.3$  [95% CI:  $-20.0, -4.3$ ]), but not in the hazardous group ( $B = -4.6$ , [95% CI:  $-12.5, 3.5$ ]). Therefore, a one-unit increase in job strain was associated with a 14.5-point increase in MSUE score for the 'safe' physical demand group, and with a 1.2-point and 9.9-point increase in MSUE scores for the 'action' and 'hazardous' physical demand groups, respectively, after adjusting for confounders (Table 2). Due to the antagonistic interaction, the slope of the safe group is steeper than the slope of the action group (Figure 2(A)).

### Sensitivity analysis: interaction among psychological job demands, job control, and physical demands on MSUE

Sensitivity analysis was done using psychological job demands and job control as separate exposures instead of job strain in model 4. Results showed that the three-way interaction among TLV for HA, psychological job demands, and job control on MSUE was significant after adjusting for confounders. Figure 2(B) displays the estimated effects of the interaction between TLV for HA and job control on MSUE. As job control increases, the MSUE score decreases in the 'safe' physical demand group, but the slope of higher psychological job demands is steeper than the slope of lower psychological job demands (Figure 2(B), left

**Table 3.** Results of multilevel linear regression for limited work performance score (range 0–100; based on QuickDASH-work module;  $n = 1450$  observations across 713 individuals in 12 companies)<sup>a</sup>.

	Models using Strain Index		Models using TLV for HA	
	Model 5	Model 6	Model 7	Model 8
Fixed effects	Coeff (95%CI)	Coeff (95%CI)	Coeff (95%CI)	Coeff (95%CI)
Job strain	11.2 (7.7, 14.4)	18.5 (12.5, 24.2)	11.1 (7.7, 14.5)	17.7 (12.1, 23.8)
Physical demands				
Safe	–	–	–	–
Action	1.2 (–0.8, 3.1)	10.4 (2.6, 18.5)	–0.01 (–2.1, 2.3)	8.9 (0.5, 17.0)
Hazardous	–0.01 (–1.9, 1.9)	10.1 (2.2, 17.7)	0.7 (–1.3, 2.8)	8.7 (1.5, 16.3)
Safe × Job strain		–		–
Action × Job strain		–10.7 (–19.5, –2.2)		–10.3 (–19.5, –1.0)
Hazardous × Job strain		–11.6 (–20.0, –3.0)		–9.2 (–17.6, –1.6)
Random effects (intercepts)				
Between individuals in a company	41.2 (5.0, 7.4)	39.5 (4.9, 7.2)	41.1 (5.0, 7.5)	40.1 (4.9, 7.3)
Between companies	0.4 (0.0, 1.6)	0.3 (0.0, 1.6)	0.6 (0.0, 1.8)	0.8 (0.0, 1.8)
Residual	161.2 (12.1, 13.3)	161.3 (12.1, 13.3)	161.4 (12.1, 13.3)	161.1 (12.1, 13.3)
Loglikelihood	–5888.9	–5884.1	–5889.5	–5886.3

<sup>a</sup>TLV for HA: Threshold Limit Value for hand activity. All models were adjusted for gender, age, survey wave (a categorical term), and musculoskeletal disorders in upper extremities (carpal tunnel syndrome, thoracic outlet syndrome, hand/wrist tendinitis, epicondylitis, trigger finger, and rotator cuff syndrome) at baseline. To identify a parsimonious model, the confounders (education, race/ethnicity, comorbid medical condition, smoking status, co-worker support, job security, and tenure) that did not provide significant impact on model fit were deleted.

panel). In the ‘action’ physical demand group, the protective effect of increased job control is attenuated and eventually disappears as psychological job demand scores increase from 24 to 30 (Figure 2(B), middle panel). In the ‘hazardous’ physical demand group, increasing job control is protective only in the group of workers with a psychological job demand score of 30 (Figure 2(B), right panel).

### The effect of physical demands and job strain on limited work performance

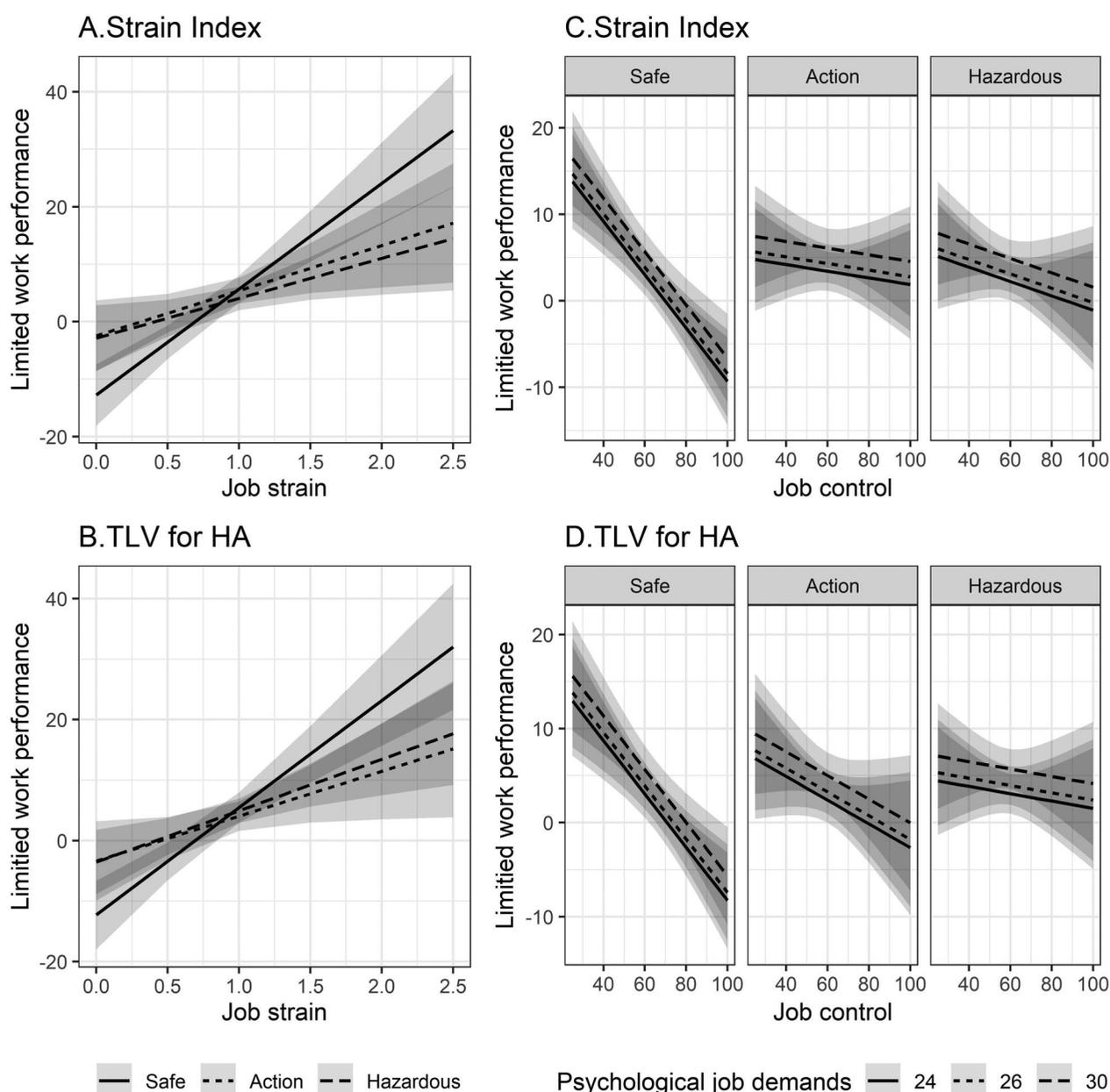
The results on limited work performance are presented in Table 3 and Figure 3. For physical demands, SI (model 5 and model 6) and TLV for HA (model 7 and model 8) were used in analysis. Job strain showed a statistically significant effect on limited work performance across all four models after adjusting for gender, age, survey wave, and previous MSDs in upper extremities at baseline. However, the effects of physical demands on limited work performance were statistically significant only in models 6 and 8.

A statistically significant interaction was observed between the SI and job strain on limited work performance ( $p = .009$ ) and between TLV for HA and job strain on limited work performance ( $p = .03$ ). Model 6 indicated that the interaction between job strain and SI was significant in the action group ( $B = -10.7$ , [95% CI:  $-19.5, -2.2$ ]) and in the hazardous group ( $B = -11.6$ , [95% CI:  $-20.0, -3.0$ ]) compared to the safe group. Therefore, a one-unit increase in job strain was associated with an 18.5-point increase in limited work performance in the ‘safe’ group, and with a 7.8-point and

6.9-point increase in limited work performance for the ‘action’ and ‘hazardous’ physical demand groups, respectively, after adjusting for confounders. Similarly, model 8 indicated that the interaction between TLV for HA and job strain was significant in the action group ( $B = -10.3$ , [95% CI:  $-19.5, -1.0$ ]) and in the hazardous group ( $B = -9.2$ , [95% CI:  $-17.6, -1.6$ ]) compared to the safe group. Therefore, a one-unit increase in job strain was associated with a 17.7-point increase in limited work performance in the ‘safe’ group, and with a 7.4-point and 8.5-point increase in limited work performance for the ‘action’ and ‘hazardous’ physical demand groups, respectively, after adjusting for confounders. Also, the impact of job strain on limited work performance was not statistically different between the action and the hazardous group in model 6 and 8. Figures 3(A,B) showed that the slope of the safe group is steeper than the slope of the action or the hazardous group due to the antagonistic interaction between job strain and physical demands.

### Sensitivity analysis: interaction among psychological job demands, job control, and physical demands on limited work performance

Sensitivity analysis was done using psychological job demands and job control as separate exposures instead of job strain in models 6 and 8. Results showed that the effect of interactions between physical demands (for both the SI and TLV for HA) and job control on limited work performance was significant after adjusting for psychological job demands and confounders. Figures 3(C,D) displays the estimated effects of the interaction. As job control increases, the limited work performance



**Figure 3.** Estimated value of limited work performance score (A: Interaction between job strain and Strain Index, B: Interaction between job strain and TLV for HA [Threshold Limit value for hand activity], C: Interaction between job control and Strain Index, D: Interaction between job control and TLV for HA) [Shaded areas indicate 95% confidence intervals].

scores decline rapidly in the 'safe' group (Figures 3(C,D), left panel). In the 'action' and 'hazardous' physical demand group (for both the SI and TLV for HA), the protective effect of increased job control is attenuated (Figures 3(C,D), middle and right panels). As psychological job demand scores increase from 24 to 30, limited work performance increased given the same job control and physical demand groups.

## Discussion

This study investigated the interaction between physical demands and job strain on MSUE and limited

work performance. This study found a significant difference only between the safe and the action groups on MSUE and the impact of job strain on MSUE was greater in the safe group than in the action group. This relationship was found when level of physical demands was measured by TLV for HA, but not by the SI. This study observed similar but more conclusive interactions for limited work performance. The impact of job strain on limited work performance was smaller in the action and the hazardous group compared to the safe group. The main source for these interactions between job strain and physical demands was from

the component of job control. The protective effect of job control was significant in the safe group but not in the action or the hazardous group. These results are in line with a prior study that showed that the protective effect of job control on musculoskeletal symptoms was significant in low physical exposures but not apparent in high physical exposures among nursing home workers (Hollmann, Heuer, and Schmidt 2001). However, these are contradictory to a majority of previous studies that showed an excess risk due to the interaction between physical demands and job strain (Devereux, Buckle, and Vlachonikolis 1999, Devereux, Vlachonikolis, and Buckle 2002, Devereux et al. 2004; Harris-Adamson et al. 2016; Sabbath et al. 2013; Widanarko et al. 2015b, 2015a) and between physical demands and job control (Gustafsson et al. 2020; Helgesson et al. 2020).

This study showed the antagonistic interaction between physical demands and job strain on MSUE and limited work performance. The reason of these results may be because of the high correlation between physical demands and job strain in this study sample. Several studies indicate two plausible reasons for the correlation between the physical and psychosocial factors. One possible reason is that the co-occurrence of physical demands and psychosocial job factor (high job demands, low job control) does not happen by chance but by the organisation of work (Punnett 2014). High physical jobs structurally involve high psychological job demands and low job control (Kausto et al. 2011). This trend is evident among blue-collar workers, where a high correlation was observed between job strain and repetitive work (MacDonald et al., 2001). On top of that, Vandergrift et al. (2012) reported a moderate correlation between physical demands and psychological job demands among automobile manufacturing workers. In this study, the action and the hazardous groups were more likely to report lower job control and higher job strain than the safe group. However, only the hazardous group of the SI showed higher psychological job demands than safe group. The other possible reason is that it could be due to measurement problems between physical factors and job strain. Psychological job demand items from JCQ questionnaire about working hard or working fast can be perceived as physical efforts by workers (Choi et al. 2012; Punnett 2014). Also, one job control item from JCQ questionnaire, engaging in repetitive work, can overlap with physical demands either SI or TLV for HA.

Our findings showed observable interactions between job control and physical demands on limited work performance and MSUE. The protective effect of job control on limited work performance was lower

both in the action and the hazardous group than the safe group. However, the protective effect of job control on MSUE was lower only in the action group compared to the safe group. It can be interpreted that job control measured by JCQ (Karasek and Theorell 1990) may buffer only psychological job demands but not physical demands. According to Häusser et al. (2010), job control can buffer job demands only when they have qualitatively identical dimensions. While psychological job demands and job control derived from the same instrument and are to measure identical dimensions, physical demands may have unmatched dimensions with job control. If the job among the action or the hazardous group consists mostly of physical demands rather than psychological job demands, providing more job control may not attenuate risk of the hazards on WMSDs among the action or the hazardous group.

Other types of job control may be essential to alleviate effects for workers exposed to physical demands. Rosen and Wischniewski (2019) reviewed the concept of job control among manufacturing industries in occupational health studies and classified the concept of job control into vertical and horizontal task characteristics of job control (vertical and horizontal job control, hereafter). Vertical job control is equivalent to decision latitude by Karasek and Theorell (1990) comprised of skill discretion and decision authority. Horizontal job control is equivalent to job control by Jackson et al. (1993) considering timing control and method control. The protective effect of vertical job control was lower among workers exposed to high physical demands in Hollmann, Heuer, and Schmidt (2001) and this study. In a study by Harris-Adamson et al. (2016), vertical job control did not significantly attenuate the estimated effect of forceful hand exertion on the rate of carpal tunnel syndromes. On the other hand, horizontal job control buffered the awkward posture on disability pension (Gustafsson et al. 2020) and on sickness absence (Helgesson et al. 2020) among care assistants. Interestingly, these two studies did not find the same relationships in nursing professionals. This calls for future studies in exploring a specific dimension of job control depending on occupations.

In this study, why the impact of job strain on MSUE was not statistically different between the safe and the hazardous group of TLV for HA may be due to the healthy worker effect. The hazardous group of TLV for HA showed declined MSUE scores in the follow-up visits compared to baseline (12.2-baseline, 9.9-one year after, 9.9-two year after,  $p=0.03$ ), while the action

and the safe group of TLV for HA showed similar MSUE scores. Those who already suffered from MSUE might have left the studied workplace or changed jobs to ones with lower physical workloads. In this study, 47% of workers in the hazardous group of TLV for HA participated in only one survey wave. This is because 74% of those left the studied workplace. In comparison, 44% and 38% of workers in the action and safe group of TLV for HA participated in only one survey wave, and 65% and 70% of each of those left the studied workplace. It is plausible that healthy workers make up more of the hazardous groups, while workers with MSUE may have moved to the action-level or safe-level group (i.e. for light duty jobs) when their disabilities have not fully recovered. In addition, frequent job changes occurred from the hazardous group to lower physical groups during the study period (34 cases from the hazardous to lower physical group, 6 cases from the action to the hazardous group, 5 cases from the action to safe group, and 12 cases from safe to higher physical group).

The strengths of the study are high participation rate (65%) and that physical demands were measured individually rather than grouping them by job titles. Therefore, the level of physical demands can be varied within the same job title in the same facility. For example, laundry workers can have varied physical demand levels ranging from safe to hazardous depending on their actual job activities. The common job titles grouped to the 'hazardous' physical demand group in this study involved tasks with repetitive and high hand force, such as sawmill green chain workers, sanders in furniture manufacturing facilities, and some window making workers. The job titles grouped to the 'action' physical demand group were some assembly line workers in electronic, exercise machine, and radiator assembly facilities. Many workers with call centre duties, pharmacists, and administrative staff in hospitals and manufacturing facilities were grouped to 'safe' physical demands.

This study should be viewed in light of some limitations. Firstly, there were many lost follow-ups due to an economic recession that occurred during the data collection period. Secondly, QuickDASH and its work module were applied only to those who had MSD symptoms (at least three times or lasting a week or longer within a year) at each time point. Workers who did not meet the MSD symptom criteria did not complete the questionnaires and were assumed to not have MSUE or limited work performance, which is likely to result in information bias. Thirdly, psychosocial job factors were measured with an adapted JCQ

and a shortened Work APGAR, which may compromise the reliability and validity. The Cronbach's alpha coefficients for psychological job demands, job control, and job security were questionable (.64, .66, and .62, respectively), while the coefficient for work APGAR (.84) was good. In this study, low job security workers at baseline were laid off more a year later than high job security workers (35 vs. 29%). At least, the question regarding job security may not totally mislead the result. Fourth, while physical factors were measured again whenever a participant reported a job change, psychosocial factors were only measured annually with the outcome variables. Therefore, there is a lack of support that job strain precedes MSUE or limited work performance. Fifth, the SI can measure physical demands on the distal upper extremities, but it is limited in its ability to estimate demands on shoulders. Additionally, a recent study showed that the 1995 version of the SI, which was used in this study, did not account for tasks with a long duration and low frequency, which may pose greater risks than tasks with a short duration and high frequency (Garg, Moore, and Kapellusch 2017). Sixth, we did not conduct stratified analysis by gender due to insufficient sample size by gender per facility and only adjusted for in the analyses. This may overlook possible gender-specific effects of physical demands and psychosocial factors on the outcome (Messing, Stock, and Tissot 2009). For example, we used the same criteria for both genders in grouping 'action' and 'hazardous' physical demand groups. It can be possible that the effect of higher physical demands on MSUE and work performance may be greater in women than in men due to the gender difference in anthropometric measurement. Lastly, unmeasured personal or organisational and psychosocial work environment confounders (e.g. computer use outside work, supervisor support, exposure to workplace violence) can distort the result in any observational study. However, a study by Li et al. (2020) indicated that linear mixed models could provide unbiased estimates when there is unmeasured between-cluster confounding, or when between-cluster confounding is more dominant than within-cluster confounding. We adjusted for two clusters, within individuals and within facilities. Therefore, if the magnitude of confounding between individuals (e.g. individual mean of supervisor support) or between facilities (e.g. facility mean of supervisor support) is bigger than the one within each cluster (e.g. supervisor support per each year and the difference between facility mean of supervisor support and individual mean of supervisor support), the effect of

unmeasured confounders on the outcome may be negligible.

## Conclusions

Musculoskeletal health is essential for maintaining one's ability to work and actively participate in all aspects of life. Therefore, investigating the interaction between the effects of physical and psychosocial hazards on MSD symptoms and work performance is critical as it can lead to a better understanding of the combined effects of occupational hazards on MSDs. This knowledge can also inform more comprehensive intervention strategies to address both physical and psychosocial factors. This study provides evidence suggesting that the impacts of job strain and job control on MSUE and work performance are smaller in higher physical demand jobs due to the interaction. This finding implies that job control, consisting of skill discretion and decision authority, may not attenuate the risk of physical demands on MSUE and work performance but it may decrease the impact of psychological job demands in creating job strain. Also, the finding implies that it may be more difficult to act on the level of worker control in jobs that are structured such that work pace is set by a machine, as is the case for workers on manufacturing production lines. As a result of the structure of such jobs, break times may not be flexible, job requirements may not be modifiable, and the order in which tasks are completed may not be changeable through workers' creativity or skill.

Based on the characteristics of the job hazards present, appropriate job control should be provided to workers to decrease the impact of psychological and physical job demands on MSDs and work performance. Further studies are needed to elucidate how the interactions between physical and psychosocial hazards affect MSDs, what kinds of job control can decrease physical demands on MSDs, and how to design the work to provide workers with control over physical job demands on MSDs.

## Disclosure statement

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