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Original Article

Are Work-Related Musculoskeletal Disorders Claims Related to Risk Factors in Workplaces of the Manufacturing Industry?

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Abstract

Objectives: Varied work-related musculoskeletal disorders (WMSDs) claim rates were found between companies even when they were in the same sectors with similar sizes. This study aimed to (i) identify common risk factors for back, shoulder, hand/wrist, and knee WMSDs among manufacturing jobs, and (ii) characterize the biomechanical exposures in jobs and work organizational practices between high and low WMSD claim rate companies so that more focused, industry-specific intervention strategies may be developed.
Methods: Using historical workers' compensation data, manufacturing companies were divided into two paired groups (low and high in the lower 25%ile and higher 75%ile, respectively). On-site job evaluations were conducted in 16 companies to determine job biomechanical risk levels. Management and workers' representatives in 32 paired companies were interviewed to identify possible differences between management strategies and management/worker relationships. A total of 39 injured workers were also interviewed to gather information of self-reported injury causes and suggested preventive measures.
Results: Analyses of 432 job evaluations showed that more jobs had higher risk levels of prolonged standing and heavy lifting in the high back WMSD claim rate companies than the low claim rate ones. No high biomechanical risk factors were found to be associated with jobs in high shoulder claim rate companies. High repetition, pinch force, and Strain Index were associated with high hand/wrist WMSD claim rate companies. High work pace and job stress were common among high knee WMSD claim rate companies. There were no statistically significant differences for the organizational factors between high and low WMSD claim rate companies. Heavy lifting, fast work pace, high hand/wrist repetition, high hand force, and awkward shoulder postures were identified as major contributing factors by the injured workers.
Conclusions: High WMSD claim rate companies appeared to have more high biomechanical exposure jobs than low WMSD claim rate companies. Available job evaluation methods for the low back and hand/wrists are satisfactory in quantifying job risk levels in the manufacturing industry. Research into more sensitive job evaluation methods for the shoulder and knee are needed.

Keywords: company safety culture; ergonomics; ergonomics estimation; ergonomics intervention; exposure assessment; job hazard; psychosocial factors; WMSD epidemiology

Introduction

Work-related musculoskeletal disorders (WMSDs) have been one of the most prevalent and costly injuries occurring in US workplaces (Roquelaure *et al.*, 2004; Foley *et al.*, 2007; Anderson *et al.*, 2015; Marcum and Adams, 2017). It was conservatively estimated that WMSDs cost the United States a total of $45–54 billion annually (National Research Council—Institute of Medicine, 2001). According to Washington State workers' compensation (WC) statistics, there were over 45 000 compensable claims each year on average between 1999 and 2013 from all causes of work-related injuries and illness (Marcum and Adams, 2017). Among them, about 43% were WMSDs claims (Marcum and Adams, 2017). The direct costs (medical and non-medical costs) due to WMSDs claims exceeded $8.5 billion dollars during that period for Washington State, which accounted for 44% of all compensable claim costs (Marcum and Adams, 2017). The most influenced body parts included low back, shoulder, hand/wrist, and knee (Marcum and Adams, 2017). The manufacturing industry had the highest claim counts due to WMSDs followed by healthcare and social assistance, wholesale and retail trade, and construction (Davis *et al.*, 2014, Marcum and Adams, 2017). Understanding the major risk factors in jobs in the manufacturing industry and having the ability to identify these risk factors are important first steps for companies to develop intervention strategies to reduce the burden of WMSDs.

In examining the WC data, we have noticed that companies may have very different claim rates for WMSDs, even when comparing those in the same industry sectors and with similar numbers of employees. For example, companies in the lower 25th percentile (25%ile) of the WC compensable claims data had no WMSD claims for the back compared to 289 claims/10 000 Full-Time Employees (FTE) for those companies in the higher 95th percentile (95%ile) for the manufacturing industry in the 3-year period between 2013 and 2015 (based on unpublished Washington State Workers Compensation Data).

Based on the above-mentioned observation, we conducted an industry-wide study in the manufacturing industry in Washington State to (i) identify common risk factors for back, shoulder, hand/wrist, and knee WMSDs among manufacturing jobs, and (ii) characterize the biomechanical exposures in jobs and work organizational practices between high and low WMSD claim rate companies so that more focused, industry-specific intervention strategies may be developed.

Methods

Study design

In order to achieve the study objectives, we did the following:

(1) Performed data extractions of historical WC data to identify pairs of companies with low (WMSD claim rates in the lower 25%ile) and high (WMSD claim rates in the higher 75%ile) claims history within the same industry sector and similar company size. These were our target study companies.
(2) Conducted worksite visits to participating paired companies to document biomechanical exposures of typical jobs. This allowed us to identify common risk factors and perform job-level evaluations to determine risk levels for WMSDs of the back, shoulder, hand/wrist, and knee between the paired companies so that comparisons could be made.
(3) Interviewed company management and worker representatives to characterize company organizational factors, safety climate, and related information on injury management. This allowed us to identify possible differences between management strategies and management/worker relationships that may have influenced the work conditions and/or WMSDs leading to a WC claim.
(4) Identified injured workers with WMSD claims from the Washington State state-fund WC data and conducted interviews to obtain self-reported experiences about their injuries. This allowed us to learn about events and possible risk factors that may have caused the injuries, as perceived by the workers themselves.

The study was approved by the Washington State Institutional Review Board.

Workers compensation claims data

WC claims data were obtained for non-traumatic cumulative back, shoulder, hand/wrist, and knee disorders. Non-traumatic onset of injuries was characterized using a combination of body part, nature of injury, and non-traumatic event type codes of the Occupational Injury and Illness Classification System

(United States Department of Labor, 2014). Medical treatment and diagnosis data were extracted including Current Procedure Terminology codes (American Medical Association, 1987) and physician diagnoses by International Classification of Disease, version 9 codes (ICD-9 codes) (Centers for Disease Control and Prevention, 2011).

WMSDs were identified through three methods:

(1) A restrictive body part code and a more general diagnosis—for instance, the body part coded wrist with an ICD-9 code of 727.00 (tenosynovitis).
(2) A more generalized body part code with a diagnosis that clearly indicates the specific body part, such as a body part coded arm with an ICD-9 code of 727.05 (tenosynovitis of the hand and wrist).
(3) The coding alone clearly indicated a WMSD, such as nature code 1241 (carpal tunnel syndrome, CTS).

Claims were further assessed for specific conditions: sciatica, rotator cuff syndrome, epicondylitis, hand/wrist tendonitis, CTS, and knee bursitis. This assessment was based on specific diagnosis codes or relevant surgical procedures. Certain diagnoses, such as CTS, could be classified as either a diagnosis code or a nature code.

Historical WMSD claims data were extracted from the Washington state-fund WC claims database between 2000 and 2010 for the manufacturing industry sector as defined by National Occupational Research Agenda (Centers for Disease Control and Prevention, 2018). The claims were further subgrouped by: (i) 4-digit NAICS (North American Industry Classification System) codes (NTIS, 2007) under each of the industry sectors, (ii) company size (small: 20–49 employees, medium: 50–100, and large: more than 100 employees), and (iii) injured body part (low back, shoulder, hand/wrist, and knee). Employers with fewer than 20 employees were excluded since these companies were not required by law to maintain a safety committee. Claim frequency distributions were calculated to obtain a list of companies in the 25th percentile (25%ile) and 75th percentile (75%ile) ranges. These were the companies that we targeted for recruitment into the study. Participating companies from the 25th percentile (25%ile) (low WMSD claim companies) and 75th percentile (75%ile) (high WMSD claim companies) were paired (i) within NAICS code, (ii) by company size (small, medium, or large), and (iii) by body region (shoulder/neck, back, hand/wrist, and knee).

A second historical WMSDs claims data extraction was performed to obtain similar data between 2011 and 2015 (coincided with the worksite visit period) among the participating companies in order to study the trends of WMSDs claims (i.e. WMSDs claims in the time period of the study worksite visits). These data were compared to the originally obtained data for the period between 2000 and 2010.

Worksite job evaluation

Worksite visits were conducted among 8 paired participating companies (16 in total) to collect the needed information so that risk identifications and job evaluations could be performed. All worksite visits were conducted between 2011 and 2015.

A representative sample of jobs (i.e. proportional to the distribution of all jobs at the participating site) was selected for the job evaluations at each of the participating companies. The total number of jobs selected for the job evaluations depended on the size of the company. Twenty percent (20), 30 and 50% of the total jobs/employees were evaluated at the companies of large, medium, and small sizes, respectively.

The job evaluation process had two steps. The first step was to identify whether a risk factor presented a 'greater than minimal risk'. The operational definition of a 'greater than minimal risk' was based on the Washington State's (WA) Caution Zone Checklist (LNI, 2000a) (e.g. pinch hand force, lifting, hand overhead, etc.). Several risk factors not included in the WA Caution Zone Checklist, such as prolonged sitting and standing, would trigger limit values based on either textbook (Chengalur *et al.*, 2004) or consensus among professional ergonomists. When a risk factor did not exist or was at a lower level than the trigger limit values, it was determined that no more than minimal risk was present and no further evaluation was needed for that risk factor.

When a risk factor in a job reached the trigger limit value becoming a 'potential concern', a further evaluation (step 2) was then required. A set of well-published assessment methods together with some complimentary methods were used in this step (Table 1). Criteria for the selection of these existing job evaluation tools were:

(1) The method needs to address at least one of the WMSD risk factors and/or determine the risk level (e.g. quantifying the level, duration, and frequency of a risk factor) related to injuries of the low back, shoulder/neck, hand/wrist, and knee.
(2) The method has been previously published and publically available.
(3) The method is popularly used by researchers and practitioners in the occupational ergonomics community.

Table 1. Detailed ergonomics job evaluation methods used for WMSD risk factors identified in step 1.

WMSD risk factor	Exposure assessment method
High hand exertions (pinch grip, power grip, other hand exertions)	Strain Index,[a] Washington State Caution/Hazard Checklist,[b] Quick Exposure Check (QEC)[c]
Repetitive impact of the hand	Washington Caution/Hazard Zone Checklist[b]
Repetitive impact of the knee	Washington Caution/Hazard Zone Checklist[b]
Highly repetitive motions of the hand/wrist	Washington Caution/Hazard Zone Checklists,[b] Strain Index[a]
Intensive keying (computer work)	Washington Caution/Hazard Zone Checklists[b]
Awkward postures (upper/arm shoulder, neck, back, lower extremity)	Quick Exposure Check (QEC),[c] Washington Caution/Hazard Zone Checklists[b]
Prolonged sitting/standing	Ergonomics textbook[d]/Ergonomists Consensus
Kneeling/squatting	Washington Caution/Hazard Zone Checklists[b]
Lifting	Washington Caution/Hazard Zone Checklists,[b] American Conference of Governmental Industrial Hygienists threshold limit value-Lifting[e]
Pushing/pulling	Liberty Mutual Push/Pull Guidelines,[f] Washington Caution/Hazard Zone Checklists[b]
Carrying	Liberty Mutual Carry Guidelines,[f] Washington Caution/Hazard Zone Checklists[b]
Hand/arm vibration	Quick Exposure Check (QEC),[c] Washington Caution/Hazard Zone Checklists,[b] EU Hand/Arm Vibration Directive[g]
Whole body vibration	Quick Exposure Check (QEC),[c] European Union WBV Directive[g]
Psychosocial factors (stress, work pace)	Quick Exposure Check (QEC)[c]

[a]Moore and Garg (1995).
[b]LNI (2000a, b).
[c]David *et al.* (2008).
[d]Chengalur *et al.* (2004) and ACGIH (2005).
[e]ACGIH (2005).
[f]Liberty Mutual Group (2004).
[g]European Union (2002).

(4) The method evaluates the jobs without the need of sophisticated instruments (e.g. using electromyography) or complicated mathematical calculations (e.g. biomechanical modeling), and consequently, can be used among a relatively large population with minimal interruptions to the workers and their employers.

Ergonomists collected relevant data using these evaluation methods through on-site job observations, as well as interviewing workers and their supervisors. These data were then brought back to the laboratory where analyses were performed according to the corresponding methods. Based on these job evaluation results, risk levels for each of the selected jobs were categorized using a 3-level or 4-level risk system (low/level 1, moderate/level 2, high/level 3, very high/level 4 depending on the assessment methods). For instance, hand exertions evaluated with the Strain Index (SI) (Moore and Garg, 1995) were considered low, moderate, or high if the Stain Index is ≤3, 3–7, or ≥7, respectively. For the push/pull and carry analysis, the job risk level was considered low, medium, high, or very high if ≥75% of the female population were determined capable of doing the job, 50–75, 25–50, or ≤25%, respectively.

Management/worker interview

Interviews of management and labor representatives were conducted among 32 manufacturing companies (the 16 companies that participated in worksite visits and an additional 16 companies which were also paired by the NAICS code, company size, and claim status by body region). The same questions were asked among management and labor representatives independently. The interview instrument included questions about organizational factors and workplace safety climate.

The work organizational factors were assessed using the Organizational Culture Profile (OCP) (Sarros *et al.*, 2005). The OCP uses 28 items to create an organization culture profile of a company. It covers seven organizational aspects (performance orientation, social responsibility, supportiveness, emphasis on rewards, stability, competitiveness, and innovation). The safety climate was assessed by a method developed using Hahn and Murphy (2008). This short survey characterizes dimensions in coworker behavior norms, safety feedback, management commitment, and worker involvement in safety.

Additional information about an organization was also collected. This included management and worker turnovers; responsibility for risk identification and solution development; level of cooperation and conflict between management and workers regarding safety and health; WC experience; the use of safety incentives; employee involvement in hazard identification and remediation; injury management of workers, and the impact of the 2008–2009 Great Recession (e.g. changes in production, manufacturing technologies, products or services, and staffing).

Injured workers' interview

Interviews with injured workers occurred between 2011 and 2014. Injured workers from the manufacturing sector with WMSDs of the low back, shoulder, hand/wrist, and knee were identified from the WC claims data and approached to participate in this study. These injured workers did not have to be from the worksites that received worksite visits or interviews. Upon their agreement to participate, a structured telephone interview followed. All interviews were taped for later transcription.

The interview included questions about past and present work history, typical daily task characteristics, descriptions of injury onset, and potential preventive measures, as well as self-reported exposures to WMSD risk factors and demographics. Self-reported risks that led to the WMSD claims were summarized.

Following transcription of the audio files, QSR NVivo version 9 (QSR International, Melbourne, Australia) was used to analyze the interviews for thematic content. Open coding of interview data was performed using a crosscase analysis process to help identify patterns or trends among responses to specific questions. Codes regarding risk factors were divided into two categories: *a priori* and emergent. *A priori* codes were identified in advance, and consisted of WMSD risk factor categories that were measured empirically during the worksite job evaluations. Emergent codes were those risk factors which were reported by interviewees as significant but not identified in the job evaluation process. Each passage of text was assigned at least one code though most were assigned multiple codes. Categories and concepts were then related to each other through an axial coding process by grouping associated concepts together into major themes. Subthemes that supported overarching concepts were grouped together under these major themes, resulting in a branching structure of related topics.

Statistics

For the historical WC claims data between 2000 and 2010, claim frequency (in number of claims per 10 000 FTE) distributions were calculated and a list of companies in the 25th percentile and 75th percentile ranges were obtained. Similarly, claim frequencies were calculated using the claims data of those participating companies between 2011 and 2015, so that their claim rates could be compared within each pair.

To compare job risk factors between paired companies, we conducted univariate logistic regression analyses (SAS 9.4, SAS Institute Inc., Gary, NC, USA) using the worksite job evaluation data. The independent variables were the job risk levels of the various WMSD risk factors. The dependent variable was the claim rank status (high claim companies versus low claim companies) of the companies in a pair by body regions (i.e. controlled by the NAICS code, company size, and body region).

Response frequencies to the various management/worker interview questions were calculated. Chi-square tests were conducted to compare differences of the responses between management and worker representatives, as well as between high and low WMSD claim rate companies.

No quantitative statistics were conducted for the injured workers' interview data. Responses were ranked according to priori and emergent themes.

Results

Workers compensation claims data

Among the 16 companies that received on-site job evaluations, all company sizes (small, medium, and large) were represented, though not equally distributed (4 small, 3 medium, and 8 large size companies). According to their 4-digit NAICS code, they belonged to the following industrial sectors: sawmills and wood preservation, architectural and structural metals manufacturing, plastics product manufacturing, and other wood product manufacturing. Table 2 shows the number of claims and average annual claim rates between 2000 and 2010, which was the period of data used to identify companies as either 'high' or 'low' rate companies and between

Table 2. Summary of the WC[b] claims for the 'low rate' and 'high rate' companies.

Company designation	Body part	Average rate/10 000 FTE[c] (standard deviation)	
		2000–2010	2011–2015
'Good'[a] performers	Back	41.3 (30.1)	64.9 (55.8)
(*N* = 8)	Shoulder	22.0 (25.0)	30.2 (34.4)
	Hand/wrist	11.9 (16.6)	15.8 (25.5)
	Knee	20.6 (21.3)	10.9 (20.4)
	Overall	*95.8 (58.6)*	*121.8 (91.9)*
'Poor'[a] performers	Back	88.8 (86.6)	47.6 (34.4)
(*N* = 8)	Shoulder	45.0 (38.3)	49.0 (50.4)
	Hand/wrist	68.9 (54.2)	28.7 (35.0)
	Knee	21.3 (15.2)	8.1 (11.7)
	Overall	*224.0 (110.9)*	*133.3 (104.5)*

[a]Low rate = WMSD claim rate in the 25th percentile; high rate = WMSD claim rate in the 75th percentile.
[b]WC—workers' compensation.
[c]FTE—Full-Time Employees.

2011 and 2015 when the worksite visits and management interviews were conducted. In comparing the claim rates between the two time periods, two companies switched their designations, i.e. their claims rates for the recent period changed so that one originally classified as a 'good' performer in the pair ended up with a higher claim rate than the other one in the pair which was originally designated as a 'poor' performer, and vice versa.

Worksite job evaluation

A total of 432 jobs were evaluated among the 16 (4 companies for each of the 4 body parts) different manufacturing sites. Risk factors identified from the job evaluations on representative jobs are shown in Tables 3–6.

Back

The analyses showed that more jobs had higher risk levels of prolonged standing (2–6 h, risk level = 2) and moderately heavy lifting (WA State caution zone, risk level = 2) among the high back WMSD claim rate (HCR-back) companies than the low claim rate (LCR-back) ones (Table 3). Twenty-seven percent (27%) of jobs among the HCR-back companies required standing 2–6 h/day compared to only 10% of jobs among the LCR-back companies.

Among the HCR-back companies, 20% of the jobs were in the Washington State Caution Zone for lifting compared to only 5% of jobs among LCR-back. However, HCR-back had fewer jobs requiring longer sitting periods (2–4 and >4 h, risk levels 2 and 3, respectively) (Table 3). Among the HCR-back companies, 78% of the jobs required less than 2 h of prolonged sitting compared to 46% of jobs in LCR-back companies.

Shoulder

Based on the Washington State Caution/Hazard Zone checklists, the high shoulder WMSD claim rate (HCR-shoulder) companies had fewer jobs with higher risk lifting (Table 4) compared to the low shoulder WMSD claim rate (LCR-shoulder) companies. Only 19% of the jobs were in the Washington State Caution Zone (risk level = 2) and Hazard Zone (risk level = 3) categories in the HCR-shoulder companies compared to 60% in the LCR-shoulder group. Similar results were found when using the American Conference of Governmental Industrial Hygienists (ACGIH) Lifting threshold limit value (TLV) method (Table 4). Fewer than 5% of the jobs were in the moderate risk level (or risk level = 2) category as evaluated by the ACGIH Lifting TLV among the HCR-shoulder companies compared to about 50% among the LCR-shoulder companies. There were also fewer workers (38%) reporting moderate stress levels (risk level = 2) in the HCR-shoulder companies compared to those (61%) in the LCR-shoulder companies (Table 4).

Hand/wrist

High repetition, high pinch force, and high SI risk levels were associated with high hand/wrist WMSD claim rate (HCR-wrist) companies compared to low WMSD claim rate companies (LCR-wrist) (Table 5). Among the HCR-wrist companies, almost 21% of the jobs had an SI score of 7 or more compared to only 10% among the LCR-wrist companies. HCR-wrist companies also had more

Table 3. Comparison of job risk levels ranking (1 = low, 2 = moderate, 3 = high, 4 = very high) between high and low back WMSD claim rate companies (*N* = 2 × 8) by exposure assessment method.

Exposure assessment method	WMSD risk factor	Risk level comparison	Odds ratio (OR) (95% confidence interval)
Washington Caution and Hazard Zone Checklists	Back posture	3:1	/
		2:1	0.328 (0.380–4.637)
	Intensive keying	3:1	5.184 (0.587–45.827)
		2:1	/
	Heavy lifting	3:1	1.167 (0.316–4.308)
		2:1	**4.667 (1.233–17.655)**
Textbook/Ergonomist Consensus	Prolonged sitting	3:1	**0.283 (0.122–0.657)**
		2:1	**0.081 (0.009–0.693)**
	Prolonged standing	3:1	1.179 (0.523–2.655)
		2:1	**3.429 (1.144–10.279)**
Quick Exposure Checklist	Dynamic back postures	4:1	4.164 (0.606–28.594)
		3:1	3.747 (0.623–22.555)
		2:1	2.131 (0.384–11.814)
	Driving	3:1	3.240 (0.625–16.801)
		2:1	3.240 (0.326–32.175)
	Work pace	3:1	2.129 (0.517–8.775)
		2:1	0.421 (0.192–0.926)
	Stress	4:1	0.947 (0.269–3.342)
		3:1	0.603 (0.236–1.540)
		2:1	0.372 (0.128–1.077)
ACGIH Lifting TLV	Lifting	4:1	1.475 (0.314–6.937)
		3:1	/
		2:1	2.213 (0.387–12.640)
European Union WBV Directive	Whole body vibration	2:1	0.0474 (0.042–5.379)

/: compared but the number of counts in one or more categories were too small to calculate reliable odds ratio.
Bold text—significant effect.

jobs with a moderate risk from high pace (risk level = 2) and higher risk levels for stress (risk level: 2 or more, Table 5). HCR-wrist companies had statistically fewer jobs in the moderate risk category for power grip force (risk level = 2), as assessed by the Washington Caution/Hazard Zone Checklists (Table 5), and fewer jobs using vibrating tools, as assessed by the Quick Exposure Checklist (QEC) (Table 5). Fewer than 11% of the jobs used vibrating tools in the HCR-wrist companies compared to more than 21% in the LCR-wrist companies.

Knee

Jobs in the high knee WMSD claim rate (HCR-knee) companies required less standing (47%) and less use of foot controls (8.2%) compared to those in the low knee WMSD claim rate (LCR-knee) companies (68% for standing, and 27% for use of foot controls for >4 h without other risk factors, risk level = 3). Table 6 shows that higher standing exposure was associated with lower knee WMSD claim rates. However, more workers in the HCR-knee companies reported sometimes having difficulty keeping up with the work and with higher stress levels (Table 6). Almost 71% workers in the LCR-knee companies reported their jobs had no stress at all. This figure was less than the 31% in the HCR-knee companies.

Management/worker interview

There were no statistically significant differences in terms of responses to all questions between the management and worker representatives ($P > 0.05$). There were also no statistically significant differences for the organizational factors of cooperation, conflict and safety climate between high and low WMSD claim rate companies ($P > 0.05$). Most companies considered themselves having comprehensive safety programs. However, the descriptive responses on open-ended questions from the management and worker representatives showed

Table 4. Comparison of job risk levels ranking (1 = low, 2 = moderate, 3 = high, 4 = very high) between high and low shoulder WMSD claim rate companies (N = 2 × 8) by exposure assessment method.

Exposure assessment method	WMSD risk factor	Risk level comparison	Odds ratio (OR) (95% confidence interval)
Washington Caution and Hazard Zone Checklists	Neck posture	3:1	1.250 (0.306–5.114)
		2:1	3.500 (0.672–18.241)
	Intensive keying	3:1	/
		2:1	1.795 (0.156–20.664)
	Heavy lifting	3:1	**0.103 (0.025–0.422)**
		2:1	**0.206 (0.030–0.712)**
Quick Exposure Checklist	Shoulder/arm posture	4:1	/
		3:1	/
		2:1	/
	Work ace	3:1	/
		2:1	0.491 (0.185–1.304)
	Stress	4:1	0.364 (0.020–6.527)
		3:1	0.218 (0.042–1.130)
		2:1	**0.264 (0.094–0.744)**
ACGIH Lifting TLV	Lifting	4:1	1.333 (0.129–13.821)
		3:1	0.444 (0.026–7.559)
		2:1	**0.049 (0.10–0.239)**

/: compared but the number of counts in one or more categories were too small to calculate reliable odds ratio.
Bold text—significant effect.

that some HCR companies took more administrative, non-engineering solutions (e.g. using braces, stretch programs, and glove programs, etc.) compared to LCR companies which often had more focused engineering controls such as using cranes for heavy lifting, and automated production processes.

Incentive programs were abandoned in some companies recognizing its potential negative effects on reporting, but still practiced as an element of their safety programs in other companies. Some HCR companies reported that they had difficulty getting workers involved in making changes to improve work conditions. From the descriptive responses, we also saw that some originally designated HCR companies had been doing very proactive things in recent years because they were determined to change their poor safety records. Some management decisions might also have influenced biomechanical exposures. For instance, one interviewee mentioned that they purposely chose products so that no ‘nasty’ products would be made in their company.

Injured workers’ interviews

Ten back, 11 shoulder, 8 hand/wrist, and 10 knee claimants, for a total of 39, were interviewed. The followings are the top five major *a priori* and emergent themes identified as risk factors that caused these injuries, and possible prevention measures suggested by these injured workers.

A priority risk factors:

- Heavy lifting,
- Fast work pace,
- High hand/wrist repetition,
- High hand force, and
- Awkward shoulder posture.

Emergent risk factors:

- Work through injury,
- Heavy work load,
- Cumulative trauma due to many years of exposure,
- Awkward knee posture, and
- Poorly organized work processes.

The followings are prevention strategies suggested by the injured workers. They were mostly administrative type interventions.

- Increase staffing,
- Lower work pace,
- Better communication,

Table 5. Comparison of job risk levels ranking (1 = low, 2 = moderate, 3 = high, 4 = very high) between high and low hand/wrist WMSD claim rate companies ($N = 2 \times 8$) by exposure assessment method.

Exposure assessment method	WMSD risk factor	Risk level comparison	Odds ratio (OR) (95% confidence interval)
Washington Caution and Hazard Zone Checklists	Hand/wrist repetition	3:1	**1.951 (1.216–3.130)**
		2:1	**0.482 (0.268–0.867)**
	Pinch gripping	3:1	**2.666 (1.365–5.205)**
		2:1	0.860 (0.667–2.769)
	Power gripping	3:1	0.858 (0.463–1.627)
		2:1	**0.185 (0.053–0.648)**
	Hand/arm vibration	3:1	0.475 (0.187–1.209)
		2:1	**0.422 (0.206–0.864)**
Quick Exposure Checklist	Hand/wrist postures	4:1	1.571 (0.198–12.470)
		3:1	0.884 (0.122–6.416)
		2:1	0.864 (0.119–6.296)
	Hand vibration	3:1	0.475 (0.187–1.209)
		2:1	**0.422 (0.206–0.864)**
	Work pace	3:1	2.816 (0.989–8.017)
		2:1	**3.509 (2.204–5.586)**
	Stress	4:1	**2.874 (1.174–7.035)**
		3:1	**2.078 (1.173–3.682)**
		2:1	**3.035 (1.845–4.991)**
Strain Index	Hand activity	4:1	**2.238 (1.225–4.086)**
		3:1	1.663 (0.831–3.329)
		2:1	0.584 (0.293–1.162)

/: compared but the number of counts in one or more categories were too small to calculate reliable odds ratio.
Bold text—significant effect.

- Provide proper tools and equipment, and
- Rotate jobs/tasks.

Discussion

Back

It is well known that there is a clear relationship between low back disorders and certain biomechanical and psychosocial factors in workplaces (NIOSH 1997, National Research Council—Institute of Medicine, 2001; Menzel, 2004; Wells *et al.*, 2004; Waters *et al.*, 2008). Our injured workers' interviews revealed that heavy lifting is believed to be the primary cause of their injury. Comparing the job evaluation results between HCR-back and LCR-back companies shows that there were more jobs in the HCR-back companies requiring more heavy lifting and prolonged standing. While there is strong evidence that heavy lifting increase back injuries (e.g. NIOSH, 1994; ACGIH, 2005), only a few studies showed relationships between prolonged standing and low back disorders (Gallagher *et al.*, 2014; Garcia *et al.*, 2015). So far there are no widely accepted guidelines pertaining to prolonged standing duration. In this study, a guideline from a textbook (Chengalur *et al.*, 2004) was used, however, this guideline does not have strong epidemiological study data to support it. Garcia and her colleagues found that the effects of muscle fatigue after about 5 h of standing work are likely to contribute to lower extremity and/or low back disorders (Garcia *et al.*, 2015).

Reducing exposure to the contributing WMSD risk factors is one of the keys in effective interventions. There are various types of ergonomics interventions that are suggested such as engineering controls, administrative measures, and programs designed to modify individual factors and combinations of these approaches (National Research Council—Institute of Medicine, 2001). Most participating companies in this study reported having comprehensive safety programs. Although details of these programs were not asked for, descriptive responses to open-ended questions from the management and worker representatives showed that some HCR companies adopted more administrative, non-engineering

Table 6. Comparison of job risk levels ranking (1 = low, 2 = moderate, 3 = high, 4 = very high) between high and low knee WMSD claim rate companies ($N = 2 \times 8$) by exposure assessment method.

Exposure assessment method	WMSD risk factor	Risk level comparison	Odds ratio (OR) (95% confidence interval)
Washington Caution and Hazard Zone Checklists	Heavy lifting	3:1	1.556 (0.576–4.198)
		2:1	1.600 (0.464–5.516)
Textbook/Ergonomist Consensus	Prolonged standing	3:1	**0.346 (0.128–0.934)**
		2:1	0.589 (0.143–2.424)
	Repetitive foot control use	3:1	0.419 (0.066–2.670)
		2:1	**0.228 (0.066–0.790)**
Quick Exposure Checklist	Driving	3:1	0.409 (0.071–2.363)
		2:1	2.455 (0.245–24.620)
	Work pace	3:1	/
		2:1	**3.946 (1.498–10.394)**
	Stress	4:1	/
		3:1	**8.700 (1.664–45.488)**
		2:1	**3.287 (1.210–8.928)**
European Union WBV Directive	Whole body vibration	2:1	0.551 (0.087–3.468)

/: compared but the number of counts in one or more categories were too small to calculate reliable odds ratio.
Bold text—significant effect.

solutions compared to LCR companies, which often had more focused engineering controls. Injured workers also suggested providing proper tools and equipment as one of the prevention strategies. It should be noted that it is well accepted that engineering controls are the most effective means in controlling WMSD risks (Van Eerd et al., 2015), however, administrative controls are often used because it usually requires less capital investment. Job rotation is also one of the suggested prevention strategies by the injured workers. Although, in theory, administrative controls can be effective, it has not been proven effective in a recent large study among US companies (Bao *et al.*, 2016a, b). The problems with some of the administrative interventions might be limited feasibility in workplaces and improper application of these methods (e.g. change jobs by job titles rather than by aimed at reducing exposures by body parts).

Shoulder

Based on a NIOSH review, there is evidence for a positive association between shoulder MSDs and highly repetitive work, repeated or sustained shoulder postures with greater than 60 degrees of flexion or abduction (NIOSH, 1997). Recent reviews also confirm that these physical determinants are associated with neck/shoulder MSDs (Côté, 2012). In the present study, awkward shoulder postures were reported by injured workers as the causative risk factor of their injuries. Awkward shoulder postures were evaluated using the QEC (David *et al.*, 2008) and Washington State Caution/Hazard Zone Checklists (LNI, 2000a, b) in the present study. However, we could not find any postural risk differences between the high and low shoulder claim rate companies. Possible explanations might be that (i) the current ergonomics job evaluation methods for the shoulder are not sensitive enough to quantify shoulder postural risk levels, or (ii) other factors other than awkward shoulder postures may be responsible for many of the shoulder injuries in the manufacturing industry.

It is interesting to see that there were fewer jobs with high lifting risks in the HCR-shoulder companies compared to the LCR-shoulder companies. This may suggest that heavy lifting is not the primary cause of most of the shoulder WMSD claims in the manufacturing industry. According to the same NIOSH review mentioned above (NIOSH, 1997), there is insufficient evidence for a positive association between force and shoulder WMSDs based on available epidemiologic studies. It is difficult to know based on the data of the present study what the primary causes for the shoulder WMSD claims in the manufacturing industry are. Further epidemiological studies are needed to understand relationships between potential risk factors and shoulder WMSDs. More sensitive job evaluation methods for the shoulder region are also needed.

While studies have shown that high job stress is associated with upper extremity MSDs (Bongers *et al.*, 2002), our data failed to link high job stress to high shoulder claim rate companies. What we found were that moderate job stress levels are linked to low shoulder claim rate companies. This is probably due to the fact that most of the jobs in these manufacturing companies that we studied did not create very high stress levels.

Hand/wrist

A number of well established job evaluation tools for the hand/wrist regions are available such as the SI and the ACGIH TLV for Hand Activity Level (Moore and Garg, 1995; ACGIH, 2001). Both the SI method and the Washington State Caution/Hazard Zone Checklists were able to show statistically significant differences between the HCR-wrist and LCR-wrist companies in the present study. Both of the methods reached the same conclusion that high exposures hand risk factors (high repetition, high hand force hence high SI) are associated with HCR-wrist companies. This is consistent with many epidemiological studies (NIOSH, 1997) which provides evidence of a positive association between these factors and hand/wrist MSDs (e.g. CTS and hand/wrist tendinitis). Injured workers also voiced that fast work pace, high hand/wrist repetition, and high hand force are responsible for their hand/wrist injuries.

While there is evidence of a positive association between jobs involving hand/wrist vibration and CTS (NIOSH, 1997), our results showed that fewer jobs used vibrating tools in high hand/wrist claim rate companies compared to low hand/wrist claim rate companies. One possible explanation to this might be that using power tools may help reduce high hand force exertions, hence reducing hand/wrist WMSD risks.

Knee

While work-related knee injuries are also common in the manufacturing industry, the only evaluation method we could use in this study was from the Washington State Caution/Hazard Zone Checklists, in which only kneeling and squatting posture are evaluated. Although kneeling and squatting are considered to be two of the primary risk factors correlated to work-related knee disorders, a review paper summarized that there are 12 other risk factors that should also be considered (Reid *et al.*, 2010). Unfortunately, there are no comprehensive job evaluation methods available for properly quantifying exposures to these risk factors. While awkward knee posture was reported as a risk factor causing their knee injuries by the injured workers, our worksite visits did not reveal any differences on kneeling and squatting exposures between HCR-knee and LCR-knee companies. This might be partially due to the low sensitivity of the job evaluation method we used in this study.

Prolonged standing and use of foot controls do not appear to be associated with HCR-knee companies in our study. However, fast work pace and high job stress levels seem to be more common among jobs of HCR-knee companies compared to LCR-knee companies.

Final remarks

While there are various risk factors contributing to the development WMSD in jobs of the manufacturing industry, heavy lifting, awkward shoulder postures, repetitive high hand force applications, fast work pace, and job stress may be the more common ones that are responsible for the low back, shoulder, hand/wrist, and knee WMSDs in this industry. Ergonomics intervention efforts should be focused on engineering controls to reduce or eliminate some of these risk factors. Proper staffing and appropriate work pace, as identified by injured workers may help to reduce some of the WMSD risks. If job rotation is used, the effectiveness of such solution needs to be carefully studied. Better communication is also mentioned as one of the solutions by injured workers. Improved communications between management and workers and among workers may help improve work processes and hence reduce unnecessary job steps or biomechanical exposures.

High WMSD claim rate companies appeared to experience higher biomechanical exposures among their jobs compared to low WMSD claim rate companies. These high biomechanical exposures could be partially due to the tools, machinery and work processes that they used, and/or partially due to the products that they decided to produce as mentioned by some management of the participating companies.

Job evaluation methods for the low back and hand/wrists seem to be quite comprehensive and satisfactory in quantifying risk levels in the manufacturing industry. However, methods for the shoulder and knee are lacking. Research into developing better practical job evaluation tools for these body regions are needed.

One observation of the worksite job evaluation result is that the odds ratios for the 2:1 (medium- to low-level exposure) category consistently exceed those of the 3:1 (high- to low-level exposure) category (Tables 3–6). There might be two possible reasons for this trend: (i) the healthy worker effect that those who are exposed to higher exposures might be the more capable workers, and (ii) the job evaluation methods were not developed using the WMSD claims data so that the cut-points may not be appropriate for these data (the cut-points for the high exposure level might be too high so that fewer cases were found in that category).

One of the limitations of this study is that the high and low WMSD status were determined based on historical data and the biomechanical exposures at the on-site job evaluations might have already been changed as that two of the companies have switched their status positions. While the overall results should show the trend of our findings, there might be instability for some companies when an addition or reduction of a few claims that had changed their status. This may also influence the sensitivity of finding relationships between WMSD claim rate status and biomechanical risk levels.

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Declaration

The authors certify that we have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this paper.

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