Musculoskeletal symptoms in upper extremities and work performance: Cut-off scores and interaction between biomechanical demand and psychosocial job factors

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Abstract

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Objective: The overall goal of these three dissertation studies was to fill the gap in the literature about the effect of biomechanical and psychosocial job factors on musculoskeletal symptoms in the upper extremities (MSUE) and work performance. Study 1 identified the level of musculoskeletal pain (MSP) in the upper extremities indicating lowered work performance. Study 2 examined whether coworker support, job security, and job satisfaction moderate the paths from biomechanical demand and psychosocial job strain to work performance when mediated by MSUE. Study 3 investigated the interaction between biomechanical demand and psychosocial job strain on MSUE and work performance

Methods: Secondary analysis was carried out using data from a prospective cohort study of full-time workers from nine manufacturing and three healthcare worksites in the state of Washington. Data involved 1) on-site visit individual biomechanical factor assessment; 2) health interview (health history, job history, MSUE status) by trained interviewers; and 3) self-administered psychosocial questionnaire. The level of work performance was measured by Disabilities of the Arm, Shoulder and Hand (DASH) work module. Study 1 adopted receiver operating characteristic (ROC) curve analysis to provide the cutoff for a composite MSP index to detect lowered work performance using baseline data. Study 2 utilized two-group structural equation modeling to examine the moderation effect for each path using baseline data. Study 3 applied multilevel linear regression for MSUE and work performance using data for up to two years.

Results: Study 1 showed that MSP index score of 2 (moderate or multisite) achieved the best balance between sensitivity (.79) and specificity (.69) to detect low work performance. Study 2 showed job security moderated the relationship between biomechanical job demand and MSUE ($\Delta x^2(1)$ =5.03, p=.02), with the low job security group experiencing a stronger effect on MSUE (β=.01, 95% CI: .002, .022) than the high job security group (β=-.01, 95% CI: -.020, .004). Job satisfaction moderated the relationship between MSUE and limited work performance ($\Delta x^2(1)$ =7.02, p=.01), with the high job satisfaction group (β=8.83, 95% CI: 5.27,12.40) experiencing a weaker effect on limited work performance compared to the low job satisfaction group (β=17.93, 95% CI: 11.86, 24.00). There was no significant moderation effect of coworker support on the three paths. Study 3 indicated workers in the action group (moderate biomechanical exposure) were less likely to have MSUE and limited work performance than workers in the safe group (low biomechanical exposure). Sensitivity analysis showed the buffering effect of job control was smaller in the action group than in the safe group.

Conclusions: For study 1, workers need to be encouraged to seek help when their MSP is moderate or experienced in more than one upper extremity body part. For study 2, the impact of biomechanical job demand on MSUE differ by the level of job security and job satisfaction modifies the impact of MSUE on work performance. For study 3, job control may play a greater role in MSUE experience and work performance among workers exposed to low biomechanical exposures, but less among workers exposed to high biomechanical exposures.

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DEDICATION

I dedicate my dissertation work to all fathers and mothers who work hard for their families, even in unfavorable work environments.

Chapter 1. Introduction

Musculoskeletal disorders (MSDs) refer to injuries or disorders involving muscles, nerves, tendons, joints, cartilage, and spinal discs. It is a common disease affecting one out of two adults in the United States (United States Bone and Joint Initiative, 2016; Nahin, 2015) and affects the locomotor system, typically featuring pain and decreased physical function (Briggs et al., 2016). If the work environment contributed significantly to the condition or the condition was made worse or persisted longer due to work, these conditions are referred to as work-related MSDs (Bernard et al., 1997).

Generally in occupational health, work-related MSDs indicate non-traumatic MSDs, which are distinguished in etiology as when the event or exposure leading to the case is a bodily reaction (e.g., bending, climbing, crawling, reaching, twisting), overexertion, or repetitive motion, but not when caused by slips, trips, falls, or similar accidents (National Research Council & Institute of Medicine, 2001; United States Bureau of Labor Statistics, 2015). According to the U.S. Bureau of Labor Statistics (2018), the most common mechanisms of occupational injuries or illnesses are overexertion and bodily reaction, and the most common cases are sprains/strains/tears and soreness/pain. In line with this trend, the Washington State Department of Labor and Industries (2018) reported that non-traumatic work-related MSDs accounted for 39.3% of total work injuries between 2006 and 2015.

Musculoskeletal health is essential for maintaining the ability to work and actively participate in all aspects of life. When MSDs involve long-term pain and disability, they create a formidable economic burden on both individuals and nations. MSDs were a leading cause of years lived with disability (YLDs) in 2016 among 195 countries (Vos et al., 2017), and a person with MSDs earns less than would be expected of persons with similar characteristics but no

MSDs (United States Bone and Joint Initiative, 2016). Recurrent and persistent MSDs can lead to loss of productivity in the workplace and can commonly result in early retirement (Schofield et al., 2015).

Musculoskeletal symptoms in the upper extremities (MSUE) are very prevalent and recurrent (Burton, Kendall, Pearce, Birrell, & Bainbridge, 2009). Experiencing work limitations due to MSUE is not rare. A longitudinal study followed newly-hired employees for three years and showed that 72% of workers experienced musculoskeletal pain in the upper extremities and 31% of workers had work limitations at least once during the study period (Gardner, Dale, Descatha, & Evanoff, 2014). Studies have indicated that a majority of workers continue working despite having musculoskeletal pain (MSP) (Herr et al., 2015; Walker-Bone, Reading, Coggon, Cooper, & Palmer, 2004). If MSP is not properly managed, some workers may lose work capacity and performance. Consequently, their perception may be that their job has become more demanding despite performing the same job, which can lead to suffering (Chapman & Garvin, 1999). More studies are needed on the phase of transition from MSDs without work limitations to MSDs with work limitations among currently working employees.

Content of this dissertation

The overall objective of this dissertation is to address a gap in the literature regarding the relationship among biomechanical job demand, psychosocial job factors, musculoskeletal symptoms in the upper extremities (MSUE), and work performance among currently working employees. This dissertation consists of three studies.

Study 1 (Chapter 2). Identifying an optimal cut-off point for musculoskeletal pain in the upper extremities to prevent lowered work performance

Little is known about when workers with MSP begin to experience diminished work performance before they actually stop their current work completely. The conservation of resource (COR) theory and suffering phenomenon emphasize preventing an initial loss of resources (Hobfoll, 2001). An early intervention study for MSDs in Sweden showed that intervention was not effective for patients with a history of absence from work due to MSDs (Linton et al.,1993). Thus, a point when there is a decrease in work performance, but before workers incur sick leave, may be the proper timing for intervention. The intensity of MSP and functioning limitation were associated among patients with work-related MSDs according to Turner et al. (2004), who also identified meaningful cut-off points of pain intensity for evaluating treatment success. The generic prognostic factors of MSDs are identified in systematic reviews as longer pain duration, multiple sites of pain, and higher pain intensity (Mallen, Peat, Thomas, Dunn, & Croft, 2007; Artus, Campbell, Mallen, Dunn, & Van Der Windt, 2017). As such, using a comprehensive MSP index could capture clinically meaningful changes in capacity and performance, which could then be used for timing secondary interventions in the workplace. Study 1 identified cut-off points of MSP indicating lowered work performance. The level of MSP was measured by a composite index of the intensity and number of affected sites in the upper extremities. To identify cut-off point scores for the MSP index, comparisons were made with the norms of the general U.S. working population.

Study 2 (Chapter 3). The moderating effect of psychosocial job resources on MSUE and work performance

Few studies have examined whether occupational factors modify the relationship between MSP and work performance. The biopsychosocial model of functioning and disability proposed by the International Classification of Functioning, Disability, and Health describes disability as not just a consequence of a health condition, but rather as the interaction between the individual's health condition and their environment (WHO 2001; Gatchel et al., 2007). Environmental factors, such as family relationships and mobility devices, modified the relationship between body impairment and capacity among patients with knee osteoarthritis in France (Rouquette et al., 2015). Study 2 examined whether coworker support, job security, and job satisfaction have moderation effects on three paths through which workers with MSUE might come to experience limited work performance: 1) from biomechanical demand to MSUE, 2) from psychosocial job strain to MSUE, and 3) from MSUE to limited work performance.

Study 3 (Chapter 4). Interaction between biomechanical demand and psychosocial job strain on MSUE and work performance

Understanding the interaction between biomechanical demand and psychosocial job hazards on MSDs is critical for estimating the extent of hazardous conditions. A few studies have demonstrated that combined hazards showed a stronger association than a single hazard alone with new episodes of neck and upper extremity pain in the U.K. (Devereux, Rydstedt, Kelly, Weston, & Buckle, 2004), functioning in France (Sabbath et al., 2013), and the presence of neck and shoulder pain in Indonesia (Widanarko, Legg, Devereux, & Stevenson, 2015). This knowledge will guide an approach to MSDs from assessment to intervention. Study 3 investigated the interaction between biomechanical demand and psychosocial job strain on MSUE and work performance.

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Chapter 2. **Identifying an optimal cut-off point for musculoskeletal pain in the upper extremities to prevent lowered work performance**

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Abstract

Objective: This study identified when musculoskeletal pain (MSP) in the upper extremities indicates lowered work performance to gauge when secondary prevention of musculoskeletal disorders is needed. **Methods:** 733 subjects from 12 manufacturing or healthcare facilities in Washington state participated. Level of work performance was measured by the Disabilities of the Arm, Shoulder and Hand (DASH) WORK module. Each DASH score was compared to the mean work performance among U.S. workers to determine if workers had lowered work performance. ROC curve analysis was conducted to find the cutoff in a composite MSP index (range 0-24) to detect lowered work performance. **Results:** The MSP index score of 2 (moderate or multisite) achieved the best balance between sensitivity (.79) and specificity (.69) in detecting lowered work performance. **Conclusions:** To prevent reduced work performance, minor pain in one site may require proper management.

Key words: musculoskeletal pain, work performance, cut-off point, upper extremities, musculoskeletal disorders, secondary prevention, work disability.

Introduction

Musculoskeletal disorders (MSDs) are a common disease affecting one out of two adults in the U.S.[1,2] According to the U.S. Bureau of Labor Statistics,[3] the most common mechanisms of occupational injuries or illnesses are overexertion and bodily reaction. The most common cases are sprains/strains/tears and soreness/pain. In line with this trend, the Washington State Department of Labor and Industries has reported that non-traumatic work-related MSDs accounted for 39.3% of total work injuries between 2006 and 2015.[4] When MSDs involve long-term pain and disability, they create a formidable economic burden on both individuals and society. MSDs are a leading cause of years lived with disability (YLDs),[5] and a person with MSDs earns less than would be expected for persons with similar characteristics but no MSDs.[2] In addition, recurrent and persistent MSDs can lead to loss of productivity in the workplace and commonly result in premature retirement.[6] Early intervention for MSDs can prevent long-term work disability and reduce resultant costs.[7]

Musculoskeletal pain (MSP) improperly managed among workers can their work capacity and performance. Consequently, workers with MSP might perceive an increase in the physical demands of their job, despite their job tasks not having changed. This can lead workers with MSDs to a trajectory called suffering, a maladaptive stress response that threatens the integrity of the individual, resulting in increased fear and hopelessness about the future, and prompting further disability.[8]

The conservation of resource theory[9] suggests initial resource loss begets future loss, and that loss, then, is more potent than gain. Resource loss tends to lead to further loss cycles with subsequent losses becoming more frequent and greater in extent. The aggregation and accumulation of discomforts and functional limitations activate a feedback cycle of increased stress and loss of function, which results in chronic MSP. Hence, identifying the point at which MSP indicates a meaningful loss of work functioning is essential for preventing chronic MSP. A study of early MSD intervention, comprised of medical treatments with physicians and physical therapists, showed that treatment was only effective for patients without a history of MSD-related work absences but not for patients with such a history.[10] This indicates that MSD intervention delivered before a significant loss of work functioning would prevent worse future outcomes. Among workers with MSP, identifying the point when most workers start experiencing a decrease in work performance but before they start incurring sick leave would be helpful in order to prompt secondary prevention intervention.

Early MSD research by the National Institute for Occupational Safety and Health[11] used a case definition of MSP as having at least moderate intensity symptoms in the affected body parts for a one-week duration once per month. This definition has been widely used in research.[12–14] An early MSD management research report prepared by the Institute for Musculoskeletal Research and Clinical Implementation in the U.K.[15] used a case definition of MSP as a new episode that interferes with work and lasts up to one week or, if severe, more than a day or two. A composite MSP index capturing all body parts in the upper extremities may also be useful since MSP in the upper extremities tends to involve symmetric and adjacent body parts.[16] However, only a few studies have used a composite MSP index. For example, Lee and colleagues[17] assigned 1 point when subjects met or exceeded all of the following criteria for MSP: 1) moderate intensity, 2) one-week duration, and 3) one-month frequency. They then summed the scores from three affected body parts (neck, back, shoulder) for a total score ranging from 0 to 9. Macdonald and colleagues[18,19] created another composite score with a much wider range (0-60), by multiplying the frequency (0-4), intensity (1-3), and number of affected regions amongst five body parts, neck/shoulder, hand/fingers, arms, lower back, hip/bottom/legs/feet (1-5).

Since there has been no diagnostic test to assess MSP, the status of a worker's MSP has been based on self-report, and MSD guidelines have encouraged workers to report their symptoms early to get appropriate treatment. However, MSP in the upper extremities is highly prevalent and recurrent among the general population,[20] and it may not be practical for workers to report it or seek help whenever symptoms occur. According to a study among university employees and students by Bruls and colleagues,[21] only about half of those with MSP in the upper extremities sought help when they experienced more disabilities in their daily activities or longer durations of pain compared to those who did not seek help. Little is known about when the critical time is that employees should seek help before they experience disability; nor is it known when employers or health professionals should implement secondary prevention intervention more aggressively to prevent work disability. Accordingly, a composite MSP index that is simple and straightforward for both employees and employers to use would be helpful in determining the appropriate time for secondary prevention. The purpose of this study is to derive a composite MSP index for the upper extremities and to determine cut-off scores that can predict the loss of work performance, which can then be used to establish timing of secondary prevention in the workplace.

Methods

Sample and procedures

The Safety and Health Assessment and Research for Prevention (SHARP) program in the Washington State Department of Labor and Industries collected data from 12 different manufacturing and healthcare facilities in the state of Washington in 2001. Through on-site visits, ergonomists initially grouped jobs into six biomechanical job exposure categories, comprised of two levels of hand force (high/low) and three levels of repetition (high/medium/low) for the purpose of recruiting potential study sites with sufficient variations of biomechanical exposures. To be eligible for this study, facilities had to have various biomechanical job exposure categories. Specifically, at least 20 workers had to be exposed to at least three out of the six biomechanical exposure categories. After getting approval from the Washington State Institutional Review Board, those within the facilities who were willing to participate (64.5%) were included in the study. Due to resource constraints and practicability, the study excluded employees working part-time or temporarily, working in mobile jobs (such as forklift driving), or in jobs with more than four tasks. This analysis used the baseline data of SHARP's cohort study. Of the 733 participants enrolled, those who had sudden upper extremity injuries in the last year (n=29) were excluded, and, finally, 704 participants were included in this analysis.

Measures

Musculoskeletal pain intensity

A structured interview with body map was used to collect information on right- and left-side musculoskeletal symptoms of the shoulder, elbow/forearm, and hand/wrist. If participants reported having musculoskeletal symptoms in the past 12 months, either at least three times or lasting a week or longer, additional questions were asked about the history of the injury and the intensity of each symptom. The descriptors of musculoskeletal symptoms included pain, stiffness, burning, and numbness or tingling; shoulder symptoms had additional descriptors, such as spasms and inability to raise arms. Symptom intensity within the last seven days was recorded using a five-point Likert scale (none-0, mild-1, moderate-2, severe-3, very severe-4) for each body part.

Generic prognostic factors of MSDs were identified in systematic reviews as multiple sites of pain and high pain intensity.[22,23] Therefore, it was appropriate to include a symptom intensity rating for pain in each of the affected sites in the upper extremities. After allocating scores for MSP symptom intensity in each of the six body parts, a composite MSP index was created by summing the intensities of each body part's pain, ranging from 0 to 24.

Work performance

Workers with upper extremity symptoms that had occurred (at least three times or persisted a week or longer) in the last year were asked to complete the Disabilities of the Arm, Shoulder and Hand (DASH) work module,[24] which asks four questions about the degree of difficulty when doing usual work tasks during the previous week. Participants rated their difficulties in using the usual technique for work, in working due to pain in the upper extremities, in maintaining the quality of work, and in spending the usual amount of time completing work using a five-point Likert scale (no difficulty-1, mild difficulty-2, moderate difficulty-3, severe difficulty-4, unable-5). The average of the scores for these questions was subtracted by one and multiplied by 25, resulting in total scores ranging from 0 to 100, with higher scores reflecting increased disability. Those without symptoms in the last year were not asked to complete the DASH work module and were recorded as 0. These DASH work scores were compared to the mean values for the general U.S. working population, depending on age and gender.[25,26] Workers with a higher DASH work score than the mean were grouped into a low work performance group.

Demographics and job characteristics

Age, gender, ethnicity, educational level, and comorbid conditions were collected via a self-report questionnaire. Information about biomechanical job exposures was collected through observing the usual tasks of workers.[27] Ergonomists directly observed and videotaped participants performing their usual jobs to collect right- and left-side hand force and hand repetition data. The level of biomechanical job exposures was calculated by the threshold limit value (TLV) for hand activity developed by the American Conference of Governmental Industrial Hygienists (ACGIH).[28] The level of biomechanical exposures on the hand/arm of each participant's dominant side was used to place them into one of three groups: safe (low), action (middle), and TLV (high). A modified version of the Job Content Questionnaire[29] was used to assess psychosocial job demand and job control. Three revised questions, "My job is very hectic," "I receive the training I need to do my job well," and "I can take a break when I want to," replaced "conflict demand" in the psychological job demand content area and "develop ability" and "allow decision" in the job control content area.

Four-quadrant job groups were created using the median values of psychosocial job demand and job control: 1) high strain job (high psychosocial demand and low control), 2) low strain job (low psychosocial demand and high control), 3) passive job (low psychosocial demand and low control), and 4) active job (high psychosocial demand and high control).

Statistical analysis

Descriptive statistics were used to characterize the sample. To examine whether three different body parts (shoulder, elbow/forearm, hand/wrist) had a different impact on work performance, work performance was regressed on each body parts' intensity and then the effect was forced to be equal. A model with freely estimated coefficients was compared to a model with equal coefficients by the likelihood ratio chi-square test (Table 2.1), and hand/wrist pain intensity was shown to be about 1.8 times more likely to result in low work performance than shoulder or elbow/forearm pain intensity (p=.01). Therefore, hand/wrist pain was weighted at 1.8 times that of shoulder or elbow/forearm pain, and a weighted MSP index was created, ranging from 0 to 30.4.

[Table 2.1]

Next, receiver operating characteristic (ROC) curve analysis was applied to identify cut-off points in both the unweighted and weighted MSP indices to detect low work performance. ROC curve analysis was performed to assess sensitivity and specificity at each possible cut-off value. For each weighted and unweighted MSP index score, sensitivity, specificity, and positive and negative predictive values were calculated. The ROC curve is based on statistical decision theory and is used in signal detection, psychology, and biomedical studies.[30] Using ROC curve analyses one can evaluate the accuracy of a diagnostic test and can select cut-off values.[31] The underlying assumption of ROC curve analysis is that it is a test that can discriminate between two groups depending on the status of outcome occurrence. If a test score is greater than a given cut-off value, a person is considered to have the outcome; if not, the person is considered to be free from the outcome. This result is compared to the true outcome status measured by a gold standard test. The probability of sensitivity (true positive-diseased) and the probability of specificity (true negative-healthy) are calculated for each possible cut-off value. The overall accuracy of the test can be assessed by the area under the curve (AUC). AUC falls between .5 (the test is not able to discriminate between two groups) and 1 (the test is perfectly able to discriminate between two groups). An ROC curve plot depicts sensitivity (true positive rate) versus 1 − specificity (false positive rate) by varying all possible cut-off scores. The point on the ROC curve furthest from the diagonal is the maximized Youden index (Youden index = sensitivity + specificity − 1).[32] When there is little information on prevalence in the target population and on the relative consequences of false negative and false positive test results, the Youden index has been used to select an optimal cut-off point in practice by balancing between false positives and false negatives. Predictive value provides interpretation of a given test result by combining sensitivity, specificity, and prevalence. It describes what fraction of all results are correct for a given cut-off point and a particular prevalence. Positive predictive value (PPV) is the fraction of true-positives given all positive test results, while negative predictive value (NPV) is the fraction of true-negatives given all negative test results. All analyses were conducted using open source software R with pROC[33]/CutpointR[34] packages.

Results

The aim of this study was to identify the level of MSP in the upper extremities indicating lowered work performance, which can be used to time the introduction of secondary prevention interventions for MSDs. The mean of the DASH work module score is 8.29 (SD: 14.96, median: 0, IQR: 0-12.5). After comparing individual DASH work scores to the mean scores of the U.S. working population for the same age and gender, about 30% of participants were categorized into the low work performance group. The specific means of the U.S. working population and of the subjects depending on gender and age groups are shown in Table 2.2. Demographic characteristics and MSP intensity are displayed in Table 2.3. Participants were 52% male and 59% white, as well, 48% of participants were high school graduates, 43% had been exposed to hazardous biomechanical demands, and 31% had been exposed to low strain job. The mean age and years at current company were 39.6 (SD: 10.9, median: 40) and 5.7 (SD: 6.8, median: 3) years, respectively. Those who were female (p=.001), older (p=.001), exposed to high job strain (p=.004), and diagnosed with MSDs in the upper extremities (p<.001) were usually grouped into the low work performance group.

[Table 2.2] [Table 2.3]

High pain intensity was observed mostly in the hand, followed by the shoulder and elbow/forearm. Workers in the low performance group had higher MSP intensity across the six body parts compared to the high performance group (p<.001). The means of the number of affected body parts are 2.2 in the low work performance group and .8 in the high work performance group (p<.001). The mean of the MSP index is 4.2 in the low work performance group and 1.2 in the high work performance group (p<.001).

Cut-off point for MSP

Sensitivity, specificity, the Youden index, PPV, and NPV were calculated for each MSP index score (Table 2.4) and each weighted MSP index score (Table 2.5). A cut-off point of 2 provides the maximum Youden index from the unweighted and weighted MSP indices (sensitivity .79 and specificity .69). The areas under the ROC curve of the unweighted and weighted MSP indices for the low work performance group was the same as .81 (95% CI: .77-.84). Figure 2.1 illustrates the ROC curve plots of the unweighted and weighted MSP indices. While the weighted MSP index is a little further from the diagonal on the left side of the plotting graphs, little difference is observed between the two MSP indices. Figure 2.2 shows the distribution of the two MSP indices by work performance level and indicate where the cut-off point of 2 is situated.

[Table 2.4] [Table 2.5] [Figure 2.1] [Figure 2.2]

Discussion

A key finding of this study is that, utilizing our MSP indices for the upper extremities, the cut-off point of 2 provides the most suitable balance between sensitivity and specificity for lowered work performance. Even though unweighted and weighted MSP indices were examined, no difference was observed in selecting the maximum Youden index as 2 and its resulting sensitivity (.79) and specificity (.69). This cut-off point is applicable in cases of either moderate MSP or with more than one affected body part in the upper extremities. This is consistent with the prior conventional case definition of MSD as moderate intensity,[12–14,17] but it adds mild, widespread pain.[22,23] AUC was .81 and within the range from .8 to .9 to be considered as excellently discriminating between the low and high work performance groups .[35]

Little has been reported about the prevalence of lowered work performance due to MSP in the upper extremities. However, one study did report that 15% of newly hired construction and service workers reported they experienced a work limitation due to MSP in the upper extremities.[36] In this study, about 30% of workers reported low work performance, and the resulting PPV and NPV were .52 and .89, respectively, at the cut-off score of 2. About 55% of workers reported an MSP index score of less than 2. When workers are screened using the score of 2 as a cut-off point, about 52% of people with MSP higher than 2 (test results-positive) have low work performance (true outcome status-positive) and about 89% of people with MSP less than 2 (test results-negative) have high work performance (true outcome results-negative), given the 30% prevalence of low work performance. The criteria of moderate MSP or more than one affected body part indicates somewhat low PPV in this study, making the index somewhat less accurate. Nonetheless, while a sophisticated instrument may be desired for clinical purposes, a measure that is less accurate, yet simple to understand and use, may be more practical for workers and employers in workplaces. The initiation of secondary MSD prevention begins with the worker's report. To prevent work disability, it is important that workers have a simple way to be aware of their MSP status, especially when they are making determinations about contacting health professionals and seeking help from employers.

Greater scores on the MSP index were related to a decrease in work performance, consistent with prior research.[37] The low work performance group had severe intensity MSP across all body parts and had more affected regions. Even though each participant's work performance score was compared to the mean score for members of the general U.S. working population in the same gender and age group, low work performance was observed more among females, older workers, those exposed to high job strain, and those with previous diagnoses of MSDs in the upper extremities. A prior study showed that having good work ability despite experiencing MSP was related to being female, younger, and free from mental disorders as well as to having a non-strenuous job, low job strain, high supervisor support, no daytime tiredness, and no economic troubles.[38] The characteristics of the low work performance group in this study were similar to the finding of that study, with the exception of gender.

Despite the utility of our findings, this study has limitations. First, for participants who did not meet the criteria for MSP (experiencing MSP at least three times or having MSP that lasted for at least a week) in the past twelve months, MSP intensity and level of work performance were not assessed. In this analysis, they were considered as having no MSP and grouped into the high work performance group. This might have resulted in a lower observed cut-off point for MSP. Second, the MSP index was derived from data collected using verbal rating scales (VRS), which, compared to numerical rating scales (NRS) or visual analog scales (VAS), lack a ratio scale property because the interval between mild and moderate categories is not equal to the one between moderate and severe categories. Therefore, summing VRS scores for each body part may not be equivalent to scores derived from NRS or VAS. In addition, VRS may reflect other concepts, such as pain beliefs (perceived control of pain experience), pain catastrophizing (helplessness and pessimistic beliefs about pain), and pain interference (the extent of hindrance of various activities), rather than just pain intensity, which is measured by NRS or VAS.[39] Thirdly, to gain validated results for this ROC analysis, the level of work performance needed to meet a gold standard that indicates the true status of the participant's work ability. To our knowledge, there is no established gold standard for low work performance with regard to the upper extremities. The mean value of work performance in the general U.S. working population may provide acceptable reference values in the absence of a gold standard. Finally, the cut-off point of 2 may not be the optimal threshold because it does not account for the prevalence of MSP in the target population and the cost ratio of false positive and false negative results. The Youden index, with which this cut-off point was established, only accounts for sensitivity and specificity and assumes 50% prevalence and an equal cost of misclassification.[31]

Conclusions

Identifying when to institute interventions that serve to prevent chronic MSD is crucial to employees' recovery and employers' efforts to maintain worker productivity. If workers are encouraged to seek help early when experiencing at least one moderate MSP or mild multisite MSP, a comprehensive screening at a clinic or a minor temporary job accommodation (e.g., break time schedule changes from designated times to whenever their MSP is severe) can facilitate recovery and prevent suffering at work. This MSP index signifying lowered work performance could be useful for prioritizing MSD cases in workplaces and for communicating to workers about when they are encouraged to report their MSP.

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Table 2.1. Unadjusted relationship between musculoskeletal pain per body region and low work performance

	Model 1: no constraint	Model 2: equal coefficient
	Coeff (SE)	Coeff (SE)
Intercept	-1.89 (0.14)	-1.85 (0.13)
Shoulder	0.30 (0.08)	0.43 (0.04)
Elbow/forearm	0.33 (0.10)	0.43 (0.04)
Hand/wrist	0.57 (0.07)	0.43 (0.04)
Model Information		
Loglikelihood	688	696

Table 2.2. DASH (Disabilities of the Arm, Shoulder and Hand) work module scores among the general U.S. working population and participants of this study

Age	Male		Female	
	General working population Mean (SD)	Sample (N=90) Mean (SD)	General working population Mean (SD)	Sample (N=119) Mean (SD)
19-34	1.54 (6.47)	4.95 (10.88)	7.18 (17.27)	6.40 (11.82)
35-44	8.08 (18.3)	5.98 (12.73)	7.21 (14.26)	9.73 (15.87)
45-54	6.09 (15.04)	7.60 (14.14)	8.8 (19.29)	15.62 (20.03)
55-64	11.73 (23.74)	4.84 (13.76)	10.52 (20.18)	13.45 (18.63)
65-74	9.42 (18.73)	12.50 (17.68)	11.03 (18.06)	-

Table 2.3. Descriptive characteristics of participants and their musculoskeletal pain intensity (n=704)

	Low work performance (n=209)		High work performance (n=495)		
	N (%)	Mean (SD)	N (%)	Mean (SD)	P-value
Gender					
Male	90 (43%)		278 (56%)		.001

Female	119 (57%)		217 (44%)		
Age		41.59 (10.66)		38.72 (10.86)	.001
Race					
White	124 (59%)		292 (59%)		.34
Asian	41 (20%)		89 (18%)		
Hispanic	20 (10%)		72 (15%)		
Native American	7 (3%)		17 (3%)		
African American	11 (5%)		18 (4%)		
Others	6 (3%)		7 (1%)		
Education					
≤ Some high school	29 (14%)		90 (18%)		.49
High school graduate	104 (50%)		236 (48%)		
Some college	58 (28%)		122 (25%)		
≥Bachelor	18 (9%)		47 (10%)		
Years of current employment		6.25 (7.23)		5.44 (6.61)	.17
Comorbidity [1]					
No	183 (88%)		455 (92%)		.07
Yes	26 (12%)		40 (8%)		
UE MSD [2]					
No	139 (67%)		411 (83%)		<.001
Yes	70 (33%)		84 (17%)		
Threshold Limit Value for hand activity					
Safe	62 (30%)		146 (30%)		.91
Action	55 (26%)		138 (28%)		
Hazardous	92 (44%)		211 (43%)		
Psychosocial job strain					
Low strain job	47 (22%)		171 (35%)		.004
Active job	28 (13%)		76 (15%)		
Passive job	58 (28%)		133 (27%)		
High strain job	63 (30%)		93 (19%)		
Missing	13 (6%)		22 (4%)		
Pain intensity (range 0-4)					
Right shoulder		.74 (1.08)		.22 (0.59)	<.001
Left shoulder		.42 (0.86)		.17 (0.52)	<.001
Right elbow/forearm		.55 (0.99)		.13 (0.47)	<.001
Left elbow/forearm		.33 (0.77)		.12 (0.46)	<.001
Right hand/wrist		1.17 (1.17)		.34 (0.68)	<.001
Left hand/wrist		.91 (1.07)		.25 (0.61)	<.001
The number of affected body parts		2.18 (1.45)		.81 (1.15)	<.001
MSP index (range 0-24)		4.10 (3.51)		1.22 (1.93)	<.001

[1] Thyroid disease, diabetes mellitus, and rheumatoid arthritis

[2] UE MSD: musculoskeletal disorder in upper extremities such as carpal tunnel syndrome, thoracic outlet syndrome, hand/wrist tendinitis, epicondylitis, trigger finger, rotator cuff syndrome.

Weighted MSP index (range 0-30.4)	5.68 (4.52)	1.69 (2.68)	<.001

Table 2.4. Cutoffs of MSP (musculoskeletal pain) index for low work performance

MSP index	DASH (Disabilities of the Arm, Shoulder and Hand) Work				
Thresholds	Sensitivity	Specificity	Youden index	PPV	NPV
≥1	.91	.56	.48	.47	.94
≥ 2	.79	.69	.49	.52	.89
≥ 3	.60	.83	.43	.59	.83
≥ 4	.46	.88	.34	.61	.79
≥ 5	.33	.93	.26	.67	.77
≥ 6	.25	.95	.21	.69	.75
≥ 7	.20	.97	.18	.76	.74
≥ 8	.14	.98	.13	.77	.73
≥ 9	.10	.99	.09	.84	.72
≥ 10	.08	.99	.08	.85	.72
≥ 11	.06	1.00	.06	.92	.72
≥ 13	.02	1.00	.03	1.00	.71
AUC (95%CI)			.81 (.77-.84)		

Table 2.5. Cutoffs of weighted MSP (musculoskeletal pain) index for low work performance

Weighted MSP index	DASH (Disabilities of the Arm, Shoulder and Hand) Work				
Thresholds	Sensitivity	Specificity	Youden index	PPV	NPV
≥1	.91	.56	.48	.47	.94
≥ 1.8	.85	.63	.47	.49	.91
≥ 2	.79	.69	.49	.52	.89
≥ 2.8	.73	.74	.46	.54	.86
≥ 3	.71	.75	.46	.55	.86
≥ 3.6	.67	.77	.44	.55	.85
≥ 3.8	.56	.84	.40	.59	.82
≥ 4	.54	.85	.40	.61	.82
≥ 4.6	.53	.87	.40	.64	.82
≥ 4.8	.51	.88	.39	.63	.81
≥ 5	.50	.88	.38	.64	.81
≥ 5.4	.49	.89	.38	.65	.81
≥ 5.6	.43	.91	.34	.67	.79
≥ 5.8	.39	.93	.32	.70	.78
≥ 6.6	.38	.94	.30	.71	.78
≥ 7	.36	.94	.30	.72	.78
≥ 7.4	.28	.95	.23	.69	.76
≥ 7.6	.26	.95	.22	.70	.76
≥ 7.8	.24	.96	.19	.69	.75
≥ 8.6	.22	.96	.18	.69	.74
≥ 9.0	.20	.96	.16	.69	.74
≥ 9.2	.19	.97	.15	.70	.74
≥ 9.4	.18	.97	.15	.73	.74
≥ 10	.15	.97	.13	.71	.73
≥ 10.8	.13	.98	.12	.76	.73
≥ 11	.13	.99	.12	.82	.73
≥ 11.4	.11	.99	.10	.88	.73
≥ 14.2	.05	1.00	.05	.91	.71
≥ 15.8	.04	1.00	.04	1.00	.71
AUC (95%CI)			.81 (.77-.84)		

Figure 2.1. Comparison of ROC curve plots between unweighted and weighted musculoskeletal pain (MSP) index.

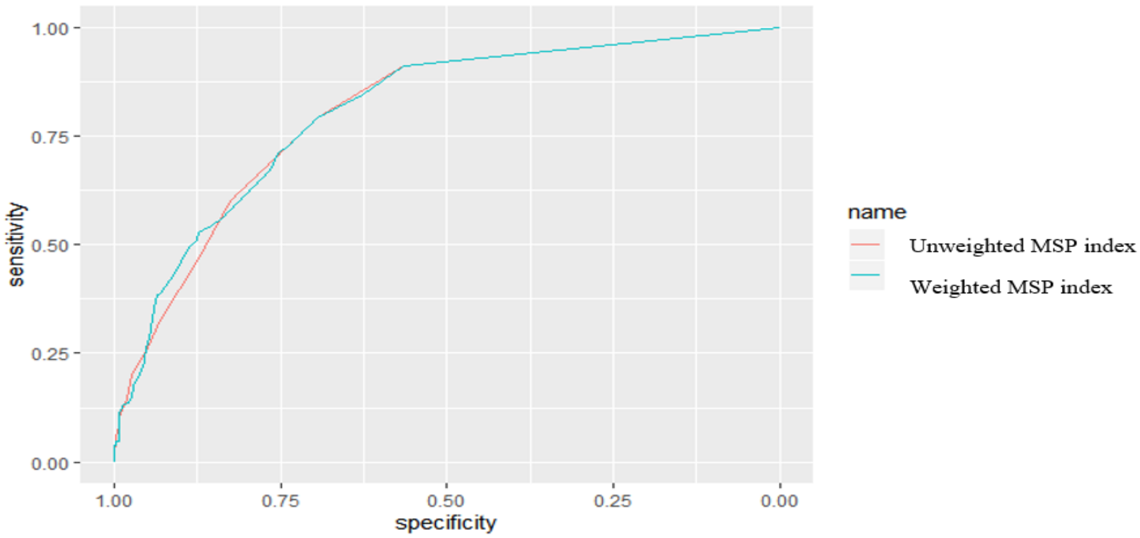
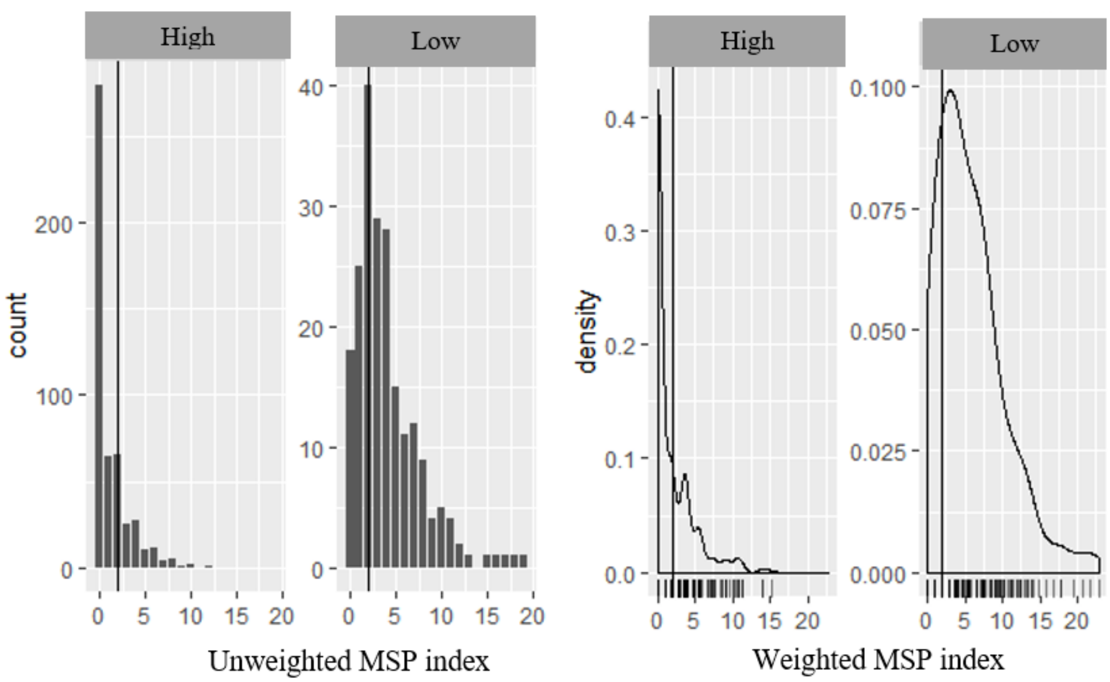


Figure 2.2. Distribution of unweighted and weighted musculoskeletal pain (MSP) index scores by the level of work performance



* Vertical lines in the distribution graph indicate the cut-off point of 2.

Chapter 3. **The buffering effect of coworker support, job security, and job satisfaction on the relationship between job demand and work performance through musculoskeletal symptoms in the upper extremities**

Target Journal: Scandinavian Journal of Work, Environment & Health
Journal Guidelines:
Abstract: 254 out of 250 words
Text (from introduction to conclusion): 4528 out of 4000 words
Tables/Figures: 5 out of 5
References: 48 out of 40

Abstract

Objectives: This study examined whether coworker support, job security, and job satisfaction moderate the path from biomechanical job demand and psychosocial job strain to work performance via musculoskeletal symptoms in the upper extremities (MSUE). Moderation effects on three paths were examined: 1) from biomechanical job demand to MSUE; 2) from psychosocial job strain to MSUE; 3) from MSUE to work performance.

Methods: This was a cross-sectional study of 669 full-time workers from nine manufacturing and three healthcare facilities. Data was collected from health interviews by trained interviewers; on-site biomechanical exposure assessments and data processing and laboratory analyses by ergonomists; and self-administered psychosocial questionnaires. Two-group structural modeling was performed to examine the interaction effect on each path.

Results: Job security moderated the relationship between biomechanical job demand and MSUE (Δx^2(1) =5.03, p=.02), with the low job security group experiencing a severe MSUE (β=.01, 95% CI: .002, .022) than the high job security group (β=-.01, 95% CI: -.02, .004). Job satisfaction moderated the relationship between MSUE and limited work performance (Δx^2(1) =7.02, p=.01), with the low job satisfaction group (β=17.93, 95%CI: 11.86, 24.00) having a stronger effect on limited work performance than the low job satisfaction group (β=8.83, 95% CI: 5.27,12.40). Coworker support had no significant moderation effect on the three paths.

Conclusions: The impact of biomechanical job demand on MSUE depends on job security, while the impact of MSUE on work performance differs based on job satisfaction. The hazards of low job security and low job satisfaction need to be controlled to prevent musculoskeletal disorders.

Key terms: job stress; work disability; musculoskeletal disorders; structural equation modeling

Introduction

Musculoskeletal disorders (MSDs) are a major occupational health problem among workers [1], regardless of whether they are work-related or not. MSDs can hamper an employee's work ability and, even worse, can lead to work accommodation or sick leave. Previous research suggests a wide range of risk factors for MSDs, but different factors may impact MSDs differently depending on the stage of severity [2]. For example, while some risk factors are critical at the onset of musculoskeletal symptoms, other risk factors become more important at the occurrence of work disability due to MSDs. Considering that musculoskeletal symptoms in the upper extremities (MSUE) are highly prevalent among the general population and recur frequently [3], working without any MSUE may be rare. In addition, a majority of workers continue working despite having MSUE [4,5], and some of them experience lost productivity [6]. Hence, disentangling occupational factors at each stage of MSUE—specifically, the development of MSUE and of work disability—is essential to conceptualize the role of the workplace in injury prevention interventions.

According to the biopsychosocial model, disability is defined as a consequence of the interaction between health, environmental, and personal factors, not just as a consequence of a health condition [7]. Within a given illness, different levels of disability may exist depending on environment. This model purports the moderation effect of occupational factors on the relationship between musculoskeletal symptoms and work disability. Even though there are many kinds of work disability, such as sick-leave or work accommodation, workers may initially experience work disability as declined work performance, or a decrease in the speed or quality of work.

Researchers have identified two principle occupational factors as risks for MSUE: biomechanical and psychosocial factors [8–10]. Based on laboratory studies, biomechanical job factors, such as work posture, force exertion, and repetition, have been considered to be a plausible biological cause for MSDs, however their effects in epidemiology studies are modest or less conclusive [3,8,9]. Psychosocial job factors that are commonly investigated within MSD studies include job demand, job control, social support, job security, and job satisfaction. While the risks of high job demand, low job control, and high job strain have been consistently shown to result in the occurrence of MSDs [9,11–15], the influence of other psychosocial factors have been less supported and investigated [10].

Recently, the Job Demand Resource (JDR) model has emerged to better understand burnout and work engagement [16], which was originally derived from the Job Demand Control (JDC) model by Karasek [17] and the Job Demand Control Support (JDCS) model by Johnson and Hall [18]. Compared to the JDC or JDCS model, JDR includes all work-related factors and divides these factors into two broad categories: job demands and job resources. Job demands are those that deplete energy and predict job strain and health impairment, whereas job resources are those that critically contribute to increasing personal growth and motivation as well as in reducing job demand. The JDR considers an interaction hypothesis between job demands and job resources, and the buffering effect of job resources was shown on burnout [19] and on musculoskeletal disorders [20].

Figure 3.1 presents a research model based on the aforementioned theoretical and empirical research. Biomechanical job demand and psychosocial job strain (the ratio of job demand and job control) were classified as job demands, while coworker support, job satisfaction, and job security were classified as job resources. Biomechanical job demand and psychosocial job strain directly relate to the severity of MSUE and limited work performance, and the severity of MSUE is directly related to limited work performance. The purpose of this study is to examine a hypothesized moderation effect of job resources on each of the following paths: (i) from biomechanical job demand to MSUE; (ii) from psychosocial job strain to MSUE; and (iii) from MSUE to limited work performance.

[Figure 3.1 here]

Methods

This cross-sectional study utilized the baseline data from a prospective cohort study conducted by the Washington State Department of Labor and Industries, Safety and Health Assessment and Research for Prevention (SHARP) program study of full-time employees in nine manufacturing sites and three healthcare facilities in the state of Washington (USA) from 2001 to 2004. This SHARP study included: 1) an individual biomechanical factor assessment by ergonomists; 2) a health interview (health history, job history) by trained interviewers; and 3) a self-administered psychosocial questionnaire. The detailed methods for the original study were previously reported [21,22]. Briefly, SHARP contacted workplaces anticipated to have varied biomechanical exposures. Specifically, each site had at least 20 workers to be exposed to jobs with ≥3 of 6 varied hand force (high/low) exposures and repetition (high/medium/low) exposures. Due to limited resources to measure biomechanical factors, SHARP researchers excluded workers had more than four tasks or mobile jobs, such as forklift driving, were excluded. Those who were willing to participate (64.5%) within the selected facilities were included in the study. The original study was approved from the Washington State Institutional Review Board. For this present secondary analysis, subjects who had a sudden injury in the upper extremities within a year prior to the start of the study were excluded.

Measures

Biomechanical job demand exposure

In the original study, certified professional ergonomists, who were blind to workers' health status, directly observed and videotaped the workers performing their usual jobs, documenting biomechanical job exposure parameters from the right and left sides of the body. The Strain Index for each side was calculated to assess the level of biomechanical job exposure. The Strain Index [23] was developed as a distal upper extremity physical exposure assessment; it is based on the product of the multipliers of six domains (intensity of exertion, duration of exertion per cycle , efforts per minute, wrist posture, speed of exertion, and duration of task per day) for each side of the body. The score of the Strain Index ranged from .0625 to 1053, and a higher score indicated strenuous physical exposure. To account for workers with multiple tasks, a time-weighted average was used for calculating the Strain Index [24].

Psychosocial job strain exposure

A modified version of the Job Content Questionnaire (JCQ) [25,26] was used to assess job demand (five items) and job control (nine items). Three revised questions (hectic, receive training, take a break) were used to replace "conflict demand" in the job demand category and "develop ability" and "allow decision" in job control category. Each response was recorded as strongly disagree, disagree, agree, and strongly agree. The total score for job demand and job control ranged from 12-48 and 24-96, respectively. A job-strain quotient term was used for the psychosocial job strain, which was computed using the ratio between two times the score of job demand and the score of job control [27]. The psychosocial job strain ranged from .25 to 4.

Effect modifiers

Job satisfaction (three items) and job security (two items) were measured by the adapted version of JCQ. All responses were recorded using a four-point Likert scale (strongly disagree-1, disagree-2, agree-3, strongly agree-4). Total scores for job satisfaction and job security ranged from 3-12 and 2-8, respectively. Work Apgar [28] was used to assess the level of support from coworkers. The original Work Apgar consists of five questions, but this study applied four questions (turn to a fellow worker for help, talk about things and share problems, accept and support each other, others respond to my emotions), all rated on a three-point Likert scale (hardly ever-1, some of the time-2, and almost always-3) with higher scores indicating higher coworker support.

Mediator

A body map was used to determine MSUE in the right/left shoulder, right/left elbow/forearm, and right/left hand/wrist. Those having MSUE (pain, aching, stiffness, burning, numbness, or tingling) at least three times or lasting a week or longer in the past year provided detailed information about MSUE intensity, while those did not were recorded as having no pain. Data about symptom intensity within the last seven days was collected using a Likert scale rating (none, mild, moderate, severe, very severe) for each body part. Due to the lack of very severe symptomatic cases amongst participants, the categories of severe and very severe were combined; accordingly, severity scores were divided into four categories: none, mild, moderate, and severe.

Outcome variable

Information on work performance was collected only from workers with MSUE at least three times or lasting a week or longer in the last year. Workers rated their ability to perform work tasks in the prior week using the four-item work module of the Disabilities of the Arm, Shoulder and Hand (DASH) [29]. The four questions asked about the difficulty of using the usual technique for work, in working with pain in the upper extremities, in maintaining the quality of work, and in spending the usual amount of time doing work. Each item was rated on a five-point Likert scale (no difficulty-1, mild difficulty-2, moderate difficulty-3, severe difficulty-4, unable-5), with global scores ranging from 0 to 100 where higher scores reflected increased disability. The score for workers who had not experienced MSUE that occurred at least three times or lasted a week or longer in the last year was assumed to be zero, no disability.

Confounders

Gender, age, smoking status (non-smoker, ex-smoker, current smoker), and previous diagnosis of comorbidities such as thyroid disease, diabetes mellitus, and rheumatoid arthritis were collected.

Statistical analysis

Since MSUE usually involves symmetrical and clustered adjacent body parts [5], interpreting the effects of occupational factors on work performance and MSUE in a specific body region, such as the hand/wrist or shoulder, may be misleading. A latent variable of the severity of MSUE was estimated based on variances and covariances from the observed severity of musculoskeletal symptoms in each body part was assessed. The analysis consisted of three steps:

1) confirmatory factor analysis and measurement invariance test for MSUE, 2) SEM for the proposed model in Figure 3.1, and 3) moderation tests of psychosocial resources. Non-response items were found in multi-item measures assessing psychosocial job strain, coworker support, job satisfaction, job security, and MSUE. To prevent the loss of observed information from participants who answered some, but not all items within a scale, multiple imputation was done at the item level [30]. After imputed the data using predictive mean matching, a total summary score for each scale was computed using observed and imputed data.

A latent variable of MSUE was constructed using symptom intensity from six body parts: right/left shoulder, right/left elbow/forearm, and right/left hand/wrist, allowing correlation between bilateral and adjacent body parts. After examining modification indices [31], the correlated errors between left hand/wrist and left shoulder were added assuming that the left extremity was usually nondominant and therefore weaker, making the impact on the left extremity more widespread than the impact on the right extremity.

Due to the skewness and kurtosis of MSUE variables, multivariate normal distribution did not hold. Therefore, MSUE from six body parts were treated as ordered outcomes and the weighted least squares means and variance adjusted (WLSMV) estimator were used. The fitness of each model was examined based on the comparative fit index (CFI) $\geq .95$, Tucker-Lewis index (TLI) $\geq .95$, and root mean square error of approximation (RMSEA) $\leq .05$ [31]. Since females reported higher MSUE than males in previous studies[3,5], there were concerns about differential response to measuring MSUE by gender. To make sure there was no measurement difference between genders, the measurement invariance test for MSUE by gender was conducted by configural (equivalence of pattern of loadings), metric (equivalence of factor loadings), and scalar invariance (equivalence of item intercepts or thresholds). After configural, metric, and scalar invariances were presented, hypothesized relationships among factors in the model can be tested [32]. To determine the measurement invariance, some researchers consider the change in approximate indices such as ΔCFI or ΔRMSEA, but there is no consensus regarding cut-off values. A difference chi-square test with a scaled and shifted test statistic [33] was applied in this study because it was more robust than changes in approximate fit indices with WLSMV [34].

SEM was constructed to examine the effects of both biomechanical job demand and psychosocial job strain on MSUE and work disability, regardless of the level of psychosocial resources, after adjusting for age, gender, smoking, and comorbidity status. Biomechanical job demand was constructed as a formative latent variable by including the right and left side of the Strain Index. The fitness of the model was examined, and coefficients and their 95% confidence intervals (CI) were computed.

To test for the moderation effect of coworker support, a two-group path analysis was performed. The sample was divided into three groups using a median score and subjects with the median value of coworker support were excluded from testing. Two models were constructed for each group: one with coefficients freely estimated and one with coefficients constrained to be equal. These two models were statistically compared via a nested model likelihood-ratio test. A significant likelihood-ratio test indicated that parameters differ across groups. The same procedure was used to examine the moderation effects of job satisfaction and job security. In the case of job security, because most people (47%) had a median score, all subjects were divided into two groups whether they were below the median or not. All analyses were conducted using the open source software R with Lavaan [35] and semTools [36] packages.

Results

Among the baseline participants of the original SHARP study, 733 participants were eligible for the present study. Those who had a sudden injury (slipping, falling, or a car accident) to the upper extremities in the last year (n=29) and those whose data had been lost for all psychosocial factor measures (psychosocial job demand, job control, job security, job satisfaction, coworker support) (n=35) were excluded. As a result, 669 workers were eligible for this analysis. Table 3.1 showed characteristics of participants. The mean age was 39 years, and most of the participants were male (52%), white (59%), high school graduates (48%), and never had been smokers (51%). Those reported comorbidities such as thyroid disease, diabetes mellitus, and rheumatoid arthritis accounted for 9% of the sample. Missing data were found for psychosocial job strain (n=40), coworker support (n=18), job satisfaction (n=15), job security (n=16), and MSUE (n=3). The prevalence of MSUE in the last seven days was 58% and the most common MSUE area was the right hand/wrist followed by the left hand/wrist, the right shoulder, and the left shoulder.

[Table 3.1 here]

Measurement model of MSUE

The latent variable of MSUE was constructed by using symptom severity from six body parts (right/left shoulder, right/left elbow/forearm, and right/left hand/wrist). The MSUE model proved to be a good fit for the data: CFI = 1.00 (criterion: $\geq$ .95), TLI = 1.00 (criterion: $\geq$ .95), and RMSEA = .00 (criterion: $\leq$ .05). Table 3.2 displays the fit indices for the models that tested measurement invariance by gender. The initial model assessing configural invariance resulted in an acceptable fit (CFI=1.00, TLI=1.01, RMSEA=.00). Testing the metric invariance also yielded a good fit and the chi-square increase was not significant compared to the configural model (Δx^2(5)

= 6.22, p=.28). Similarly, the scalar invariance model produced an acceptable fit and no significant chi-square increase (Δx^2ure(11) = 9.66, p=.56) when compared to the metric invariance model.

[Table 3.2 here]

Structural equation modeling of job demand's effect on MSUE and work performance

The model-fit for this SEM was satisfactory with CFI=.96, TLI=.98, and RMSEA=.04 (Figure 3.2). Unstandardized coefficients and 95% CIs for each path were described in Table 3. Higher psychosocial job strain led to more severe MSUE (β=.42, 95% CI: .13-.71) and greater work performance limitation (β=4.61, 95% CI: .23-8.98) after adjusting for gender, age, smoking status, and comorbidity. Because the coefficients of being a current smoker and ex-smoker were fairly similar, a binary smoking status (smoker vs. never smoked) was used in this model for parsimony. Increasing MSUE was associated with greater work performance limitation (β=13.34, 95% CI: 10.51-16.18) after controlling for job strain, biomechanical demand, gender, age, smoking status, and comorbidity. However, the effect of biomechanical demand on MSUE and work performance was not observed in this study.

[Figure 3.2 here]

Buffering effect of coworker support, job security, and job satisfaction

The estimates for each path depended on the level of coworker support, job security, and job satisfaction and were described in Table 3.3, and the results of the chi-square difference tests were presented in Table 3.4. In the two-group analysis for the level of coworker support, 297 participants were in the high support group and 288 participants were in the low support group; excluding 82 participants in the middle group. The model freely estimating for two levels of coworker support (Model 1) had a good fit with $x^2(90)$=110.7, CFI=.98, TLI=.99, RMSEA=.03. While the coefficients for the two paths, from biomechanical demand to MSUE and from MSUE to limited work performance, were similar in both the low and high coworker support groups, the coefficients for the other path, from psychosocial job strain to MSUE, were different with .54 for the high support group and .26 for the low support group. To determine whether the coefficients differed significantly between the two groups, Model 1 was compared to a model with equal path coefficients, and this comparison showed that the difference was not significant ($\Delta x^2(1)$=.74, p=.39).

[Table 3.3 and Table 3.4 here]

In the two-group analysis for the level of job security, there were 459 participants in the high job security group and 210 participants in the low job security group. The model freely estimating for two levels of job security (Model 2) had a good fit with $x^2(90)$=108.81, CFI=.98, TLI=.99, RMSEA=.25. For each additional unit of biomechanical demand, the mean MSUE was estimated to be lower by .01 (95% CI: -.02, .004) in the high job security group and to be higher by .01 (95% CI: .002, .022) in the low job security group. For each additional unit of psychosocial job strain, the mean MSUE was estimated to be higher by .74 (95% CI: .33, 1.15) in the high job security group and higher by .18 (95% CI: -.30, .66) in the low job security group. In addition, greater MSUE was significantly associated with higher limited work performance in the high job security group (β= 15.52, 95% CI: 11.7, -19.33) and in the low job security group (β=10.55, 95% CI: 6.64, 14.45). To determine whether the coefficients differed significantly between the two groups, Model 2 was compared to a model with equal path coefficients and showed that the coefficients for the path from biomechanical demand to MSUE significantly differed ($\Delta x^2(1)$ =5.03, p=.02, $\beta_{\text{high job security}}$=-.01, $\beta_{\text{low job security}}$=.01), but they did not differ significantly for the path from psychosocial job strain to MSUE ($\Delta x^2(1)$ =2.66, p=.10, $\beta_{\text{high job security}}$=.74, $\beta_{\text{low job security}}$=.18) or for the path from MSUE to limited work performance ($\Delta x^2(1)$ =2.65, p=.10, $\beta_{\text{high job security}}$=15.52 $\beta_{\text{low job security}}$= 10.55).

In the two-group analysis for the level of job satisfaction, there were 289 participants in the high job satisfaction group and 213 participants in the low job satisfaction group; 167 participants in the middle group were excluded. The model freely estimating for two levels of job satisfaction (Model 3) had a good fit with $x^2(90)$ =96.02, CFI=.99, TLI=1.00, RMSEA=.02. The estimates for each path between the low and high job satisfaction groups were described in Table 3. The coefficients for the path from biomechanical demand to MSUE were similar for both groups, while the coefficients for the other two paths were different for both groups. For every additional unit of psychosocial job strain, the predicted MSUE was higher by 40.68 (95% CI: 0.11,1.25) in the high job satisfaction group and higher by .17 (95%CI: -.47, .50) in the low job satisfaction group. In addition, greater MSUE was significantly associated with higher limited work performance in the high job satisfaction group (β=8.83, 95% CI: 5.27, 12.40) and in the low job satisfaction group (β=17.93, 95% CI: 11.86, 24.00). To determine whether the coefficients differed significantly between the two groups, Model 3 was compared to a model with equal path coefficients and showed that the coefficients for the path between MSUE and limited work performance were significantly different ($\Delta x^2(1)$ =7.02, p=.008), but they were not significantly different for the path between psychosocial job strain and MSUE ($\Delta x^2(1)$ =2.97, p=.08).

Discussion

The main purpose of this study was to examine whether job resources (job security, job satisfaction, coworker support) buffer the impacts of biomechanical job demand and psychosocial job strain on MSUE and on work performance. Job security and job satisfaction showed a buffering effect on MSUE and limited work performance, but coworker support did not. The relationship between biomechanical demand and MSUE depended on the level of job security, with a stronger effect of biomechanical demand on MSUE being experienced among workers with low job security. The relationship between MSUE and work performance depended on the level of job satisfaction, with people with higher job satisfaction being less likely to experience limited work performance compared to those with low job satisfaction.

Job insecurity was associated with higher occupational injuries and decreased safety, motivation, and compliance [37]. Job insecurity is common among people with low socioeconomic status [38], and it becomes more critical when their economic status depends on their paid work [39]. Therefore, workers with higher job insecurity are more likely to go to work when they have health conditions requiring sick leave [40]. Because workers with low job security tend to work through pain and illness, the impact of biomechanical demand on MSUE was greater on the low job security group than the high job security group. A similar relationship was observed in a study that showed that women in poultry processing with job insecurity at the baseline were more likely to have developed MSDs in the upper extremities at the follow-up [41] and a study that showed that high job insecurity was associated with frequent musculoskeletal symptoms among workers in a university and at an academic hospital [42]. The uncertainty of job security may prevent workers from managing MSUE because they are reluctant to either take sick leave or ask for work accommodation.

The present study found that, among workers with the same severity of MSUE, those who were highly satisfied with their work were less likely to experience limited work performance. To my knowledge, there is no study has examined the buffering effect of job satisfaction on the relationship between MSUE and work performance. Previous studies have shown that job satisfaction is significantly related to work performance, intention to leave [43], and intention to return to work [44]. Also, job satisfaction has been investigated as an outcome in occupational stress research, indicating that high job strain and high physical demand decrease job satisfaction [45]. The biopsychosocial model purports that the work environment plays a critical role in the relationship between MSUE and work disability. Since job satisfaction can be a factor of the overall work environment, reflecting all biomechanical and psychosocial work factors, high job satisfaction may be indicative of a favorable work environment, which in turn can buffer the impact of MSUE on limited work performance.

While social support has been regarded as a buffer in stress research, this study did not find a significant moderation effect. On the contrary, the impact of psychosocial job strain on MSUE and the impact of MSUE on limited work performance was, on average, greater in the high support group than in the low support group; however, these differences were not statistically significant. Since it is uncertain whether social support preceded MSUE or limited work performance in this cross-sectional analysis, it is possible that those who had severe MSUE and lower work performance asked for more help from coworkers. Otherwise, the buffering effect of social support for the path from psychosocial job strain to MSUE and for the path from MSUE to work performance may be different depending on the level of biomechanical demand. Joling and colleagues [20] showed social support helped protect against MSD symptoms among workers exposed to low physical demand, but this relationship was inverse or insignificant as the physical demand increased. Typically, a Strain Index less than 3 is regarded as a safe level of biomechanical exposure [24]. As such, only 33% of participants in this study could be categorized in the safe group, which means 67% of participants were exposed to high physical demand, a condition in which the buffering impact of social support could be weakened or even inverted. In the high physical demand setting, MSUE can be more common and seeking help from coworkers may be needed to get the job done within an expected timeframe. Long-term or higher support from coworkers shown to have negative effects, such as reinforcing complaint behavior along with negative and passive coping skills [46] as well as damage to one's self-esteem and autonomy [47].

The findings of this study need to be interpreted with the following limitations. First, given cross-sectional analysis, the temporality of variables does not hold and the direction of association between variables can be reversed. However, as the purpose of this study was to examine an interaction effect rather than a causal relationship, the interpretation of the results is less likely to be impacted by temporality. Secondly, this study used SEM, which requires strong assumptions compared to other analytic methods like regression. While this study waived multivariate normality because of the use of the WLMSL estimator, unmeasured confounders could easily incur bias and lead to false conclusions. Third, the Strain Index for biomechanical demand measures physical impact on the distal upper extremities but does not measure impact on the shoulders. The present study utilized a 1995 version of the Strain Index that was subsequently corrected to account for a combination of long duration and low frequency tasks, which may pose greater risk than a combination of short duration and high frequency tasks [48]. Fourth, psychosocial job factors were measured with an adapted JCQ and a shortened Work APGAR, which may compromise the reliability, and validity as well as the limits compared to standardized norms. The Cronbach's alpha coefficients for job demand and job control were questionable (.65 and .67, respectively), while the coefficient for work APGAR (.82) was good. Fifth, the magnitude of either MSUE or work performance might have been underestimated in this study. The intensity of MSUE and level of work performance were collected only from workers who had symptoms at least three times or lasting a week or longer in the prior twelve months. Workers with MSUE who failed to meet the classification requirements under this case definition were regarded as symptom-free and as having no lost work performance. Due to the possibility of information bias, the effect of biomechanical job demands and psychosocial job strain on MSUE and limited work performance could have been underestimated.

In conclusion, this study demonstrated that the effect of biomechanical demand on the severity of MSUE differed by level of job security and the effect of MSUE on work performance differed by level of job satisfaction. MSUE is very common and recurrent. The majority of workers continue working despite having MSUE and, thus, experience limited work performance. MSD prevention programs and workplace policies need to include reducing the hazards of job insecurity and providing sustainable work environments for workers with MSUE. Future studies need to call attention to populations with job insecurity and to components that lead to a satisfied work environment, even for workers with MSUE.

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thus was not subject to human subjects review by the University of Washington Human Subjects Division (Institutional Review Board).

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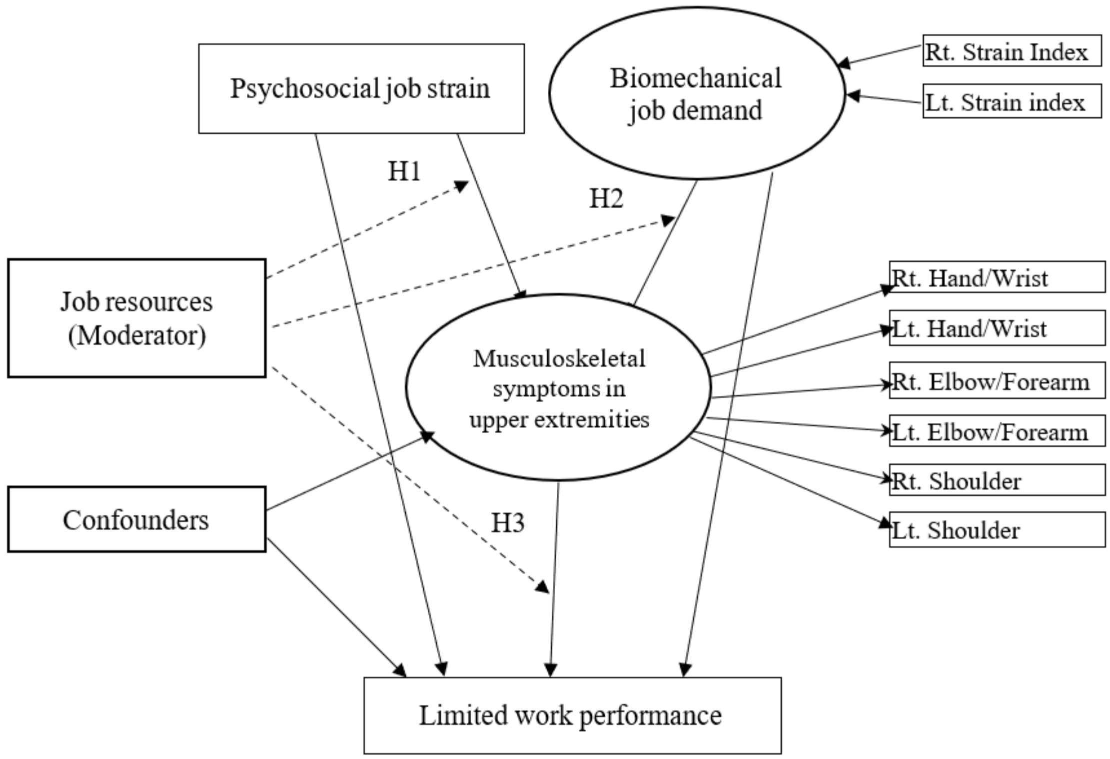
Figure 3.1. Conceptual framework and hypotheses [1]



[1] All exogenous variables such as psychosocial job strain, biomechanical job demand, age, female, smoking status, and comorbidity were allowed to covary each other if there was no a direct path between them.

Table 3.1. Characteristics of study participants (n=669)

Characteristics	N (%)	Mean (SD)
Gender		
Male	348 (52%)	
Female	321 (48%)	
Age		39.4 (10.8)
Race		
White	402 (60%)	
Asian	121 (18%)	
Hispanic	83 (12%)	
Others	62 (9%)	
Education		
Some high school or less	113 (17%)	
High school graduate	319 (48%)	
Some college or higher	237 (35%)	
Smoking status		
Non-smoker	330 (49%)	
Ex-smoker	140 (21%)	
Current smoker	199 (30%)	
Comorbidity [1]	60 (9%)	
Strain Index		
Right		13.6 (26.1)
Left		11.6 (25.6)
Psychosocial job strain		1.1 (0.3)
Coworker support		6.8 (2.2)
High (>7)	297 (44%)	
Middle (=7)	84 (13%)	
Low (<7)	288 (43%)	
Job satisfaction		9.1 (2.1)
High (>9)	289 (43%)	
Middle (=9)	167 (25%)	
Low (<9)	213 (32%)	
Job security		5.8 (1.2)
High (≥6)	459 (69%)	
Low (<6)	210 (31%)	
MSUE in last 7 days [2]		
No MSUE	284 (42%)	
Right shoulder	136 (20%)	
Left shoulder	94 (14%)	
Right elbow/forearm	71 (11%)	
Left elbow/forearm	93 (14%)	
Right hand/wrist	228 (34%)	
Left hand/wrist	182 (27%)	
Limited work performance		8.2 (14.9)

[1] Previous diagnosis of diabetes mellitus, rheumatoid arthritis, or thyroid disease

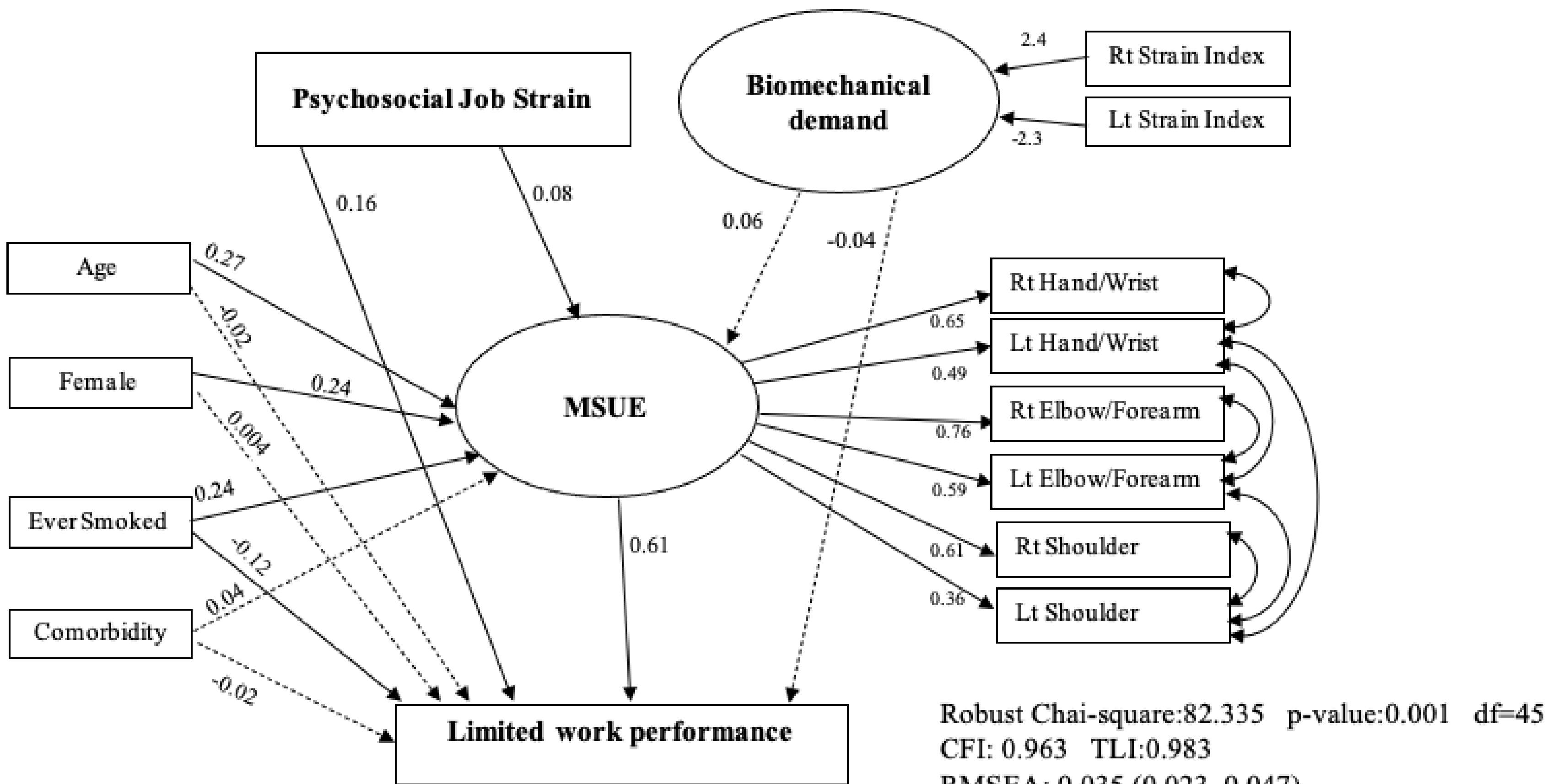
[2] MSUE: musculoskeletal symptoms in upper extremities. Symptom must be equal to or greater than a mild level.

Table 3.2. Measurement invariance tests of musculoskeletal symptoms in the upper extremities by gender

Robust fit indices	Baseline model	Configural model	Metric invariance model	Scalar invariance model
x^2 (Δx^2 [1])	2.668	4.204	11.812 (6.228)	21.254 (9.658)
df (Δdf)	3	6	11 (5)	22 (11)
P-value	-	-	.285	.561
CFI(ΔCFI)	1.000	1.000	.999 (-0.001)	1.000 (.001)
TLI(ΔTLI)	1.002	1.010	.998 (-0.012)	1.001 (.003)
RMSEA(ΔRMSEA)	.000	.000	.015 (0.015)	.000 (-.015)

[1] This is standard test statistics for a robust difference test.

Figure 3.2. Effects of biomechanical demand and psychological job strain on musculoskeletal symptoms in upper extremities (MSUE) and work performance (N=669) [1]



[1] Solid line indicates p<0.05; standard coefficients appear in each path; Rt: right, Lt: left; All exogenous variables including psychosocial job strain, biomechanical job demand, age, female, smoking status, comorbidity were allowed to covary each other if there was no a direct path between them.

Table 3.3. Estimates of job factors on MSUE and limited work performance between low and high psychosocial resources[i]

	Path		Model 0	Model 1: Coworker support		Model 2: Job Security		Model 3: Job satisfaction	
			Total (N=669) Estimate (95%CI)	High (N=297) Estimate (95%CI)	Low (N=288) Estimate (95%CI)	High (N=459) Estimate (95%CI)	Low (N=210) Estimate (95%CI)	High (N=289) Estimate (95%CI)	Low (N=213) Estimate (95%CI)
1	PJS	→ MSUE	0.42 (0.13, 0.71)	0.54 (0.11,0.97)	0.26 (-0.20, 0.72)	0.74 (0.33, 1.15)	0.18 (-0.30, 0.66)	0.68 (0.11,1.25)	0.17 (-0.47,0.50)
2	BJD		0.004 (-0.004, 0.01)	0.004 (-0.01,0.02)	0.004 (-0.01, 0.01)	-0.01[ii] (-0.02, 0.004)	0.01[ii] (0.002, 0.02)	0.005 (-0.006,0.02)	0.004 (-0.006, 0.01)
3	Age		0.02 (0.01, 0.02)	0.02 (0.01, 0.03)	0.02 (0.01, 0.03)	0.03 (0.02,0.03)	0.01 (-0.002,0.02)	0.02 (0.02,0.04)	0.02 (0.01, 0.03)
4	Female		0.32 (0.17, 0.47)	0.32 (0.09,0.55)	0.52 (0.27,0.77)	0.23 (0.04,0.42)	0.47 (0.21,0.73)	0.57 (0.28, 0.86)	0.27 (0.02, 0.53)
5	Smoke r		0.33 (0.19, 0.48)	0.34 (0.11, 0.56)	0.40 (0.17, 0.63)	0.28 (0.10,0.46)	0.42 (0.14,0.71)	0.62 (0.35,0.89)	0.23 (-0.02,0.47)
6	COM		0.01 (-0.12, 0.32)	0.24 (-0.09, 0.58)	-0.20 (-0.57, 0.18)	0.14 (-0.14,0.42)	0.05 (-0.36,0.46)	0.11 (-0.24,0.46)	0.21 (-0.19,0.61)
7	MSUE	→ LWP	13.34 (10.51, 16.18)	13.59 (10.01,17.18)	12.54 (7.60,17.47)	15.52 (11.70, 19.33)	10.55 (6.64,14.45)	8.83[iii] (5.27, 12.40)	17.93[iii] (11.86,24.00)
8	PJS		4.61 (0.23, 8.98)	6.24 (-1.64,14.12)	2.97 (-3.65,9.59)	5.26 (-2.39, 12.91)	0.96 (-5.03, 6.94)	-0.07 (-0.23,0.10)	4.28 (-4.89,13.44)
9	BJD		-0.05 (-0.17, 0.08)	-0.05 (-0.26, 0.16)	-0.07 (-0.26,0.12)	0.08 (-0.13, 0.28)	-0.12 (-0.35, 0.12)	-0.07 (-0.23,0.1)	0.03 (-0.03,0.37)
10	Age		-0.03 (-0.15, 0.09)	-0.12 (-0.30, 0.06)	0.04 (-0.17,0.26)	-0.11 (-0.29, 0.06)	0.01 (-0.18, 0.20)	-0.02 (-0.21, 0.17)	0.03 (-0.25,0.30)
11	Female		0.13	-0.78	-0.14	-1.17	2.82	1.56	-0.34

[i] PJS: psychosocial job strain, BJD: biomechanical job demand, MSUE: musculoskeletal symptoms in upper extremities, COM: comorbidity, LWP: limited work performance

[ii] The coefficients were statically different between the low and high job security group (p=.02)

[iii] The coefficients were statically different between the low and high job satisfaction group (p=.01)

		(-2.44, 2.70)	(-0.59, 3.34)	(-5.01, 4.72)	(-4.37, 2.02)	(-1.65, 7.30)	(-2.12,5.25)	(-6.25,5.56)
12	Smoker	-3.61 (-5.88, -1.34)	-3.32 (-6.85, 0.20)	-4.44 (-8.95, 0.07)	-5.44 (-8.61, -2.28)	-0.14 (-4.10, 3.82)	-2.17 (-6.22,1.89)	-5.72 (-10.57, -0.88)
13	COM	-0.90 (-3.89, 2.10)	2.20 (-0.78, 5.18)	-5.57 (-13.96, 2.83)	-0.81 (-4.46,2.85)	-1.37 (-7.08,4.35)	-2.09 (-5.71,1.53)	-2.42 (-10.53,5.68)

Table 3.4. Equality test on low and high psychosocial resources

	x^2	df	CFI	TLI	RMSEA	Hypothesis	$\Delta x^{2*}(\Delta df)$	P
Model 1: Coworker support	110.65	90	.975	.988	.028			
Model 1 with equal coefficient for path 1	110.82	91	.977	.988	.029	H1	0.74(1)	.39
Model 2: Job security	108.81	90	.983	.992	.025			
Model 2 with equal coefficient for path 1	113.99	91	.979	.990	.028	H1	2.66(1)	.10
Model 2 with equal coefficient for path 2	116.27	91	.977	.989	.029	H2	5.03(1)	.02
Model 2 with equal coefficient for path 7	112.21	91	.981	.991	.026	H3	2.65(1)	.10
Model 3: Job satisfaction	96.02	90	.991	.996	.016			
Model 3 with equal coefficient for path 1	99.95	91	.987	.994	.020	H1	2.97(1)	.08
Model 3 with equal coefficient for path 7	104.35	91	.980	.991	.024	H3	7.02(1)	.01

* This is standard test statistics for a robust difference test.

Chapter 4. **Interaction between biomechanical demand and psychosocial job strain on musculoskeletal symptoms in upper extremities and work performance**

- **Target journal:** Work & Stress
- **Journal Guidelines:**
  - Less than 30 double-spaced typewritten pages (inclusive of references, figures and tables): 37 pages
  - British spelling
  - Unstructured abstract: 211 out of 200 words
  - Specific font and line spacing options
  - First paragraph will not be indented
  - Use a zero before the decimal point when numbers are less than one. For example: t = 0.40
  - However, do not use a zero before the decimal point when the number cannot be greater than one. This occurs with correlations, proportions and levels of statistical significance. For example: r = .27, p < .01

Interaction between biomechanical demand and psychosocial job strain on musculoskeletal symptoms and work performance

Biomechanical and psychosocial job factors are risk factors of musculoskeletal disorders (MSDs). Some studies have raised the possibility of a synergistic interaction between biomechanical and psychosocial job factors on MSDs. This study aimed to investigate the interaction between biomechanical demand and psychosocial job strain on musculoskeletal symptoms in upper extremities (MSUE) and work performance. This prospective cohort study followed 713 full-time workers for up to two years, who were recruited from nine manufacturing or three healthcare facilities in Washington in the United States. Biomechanical exposure was measured by the Strain Index and Threshold Limit Value for hand activity, which were categorized as safe, action, and hazardous groups. Psychosocial job strain was calculated as the ratio of job demand and job control. Results from multilevel modelling showed the effect of job strain on MSUE and limited work performance was greater in the safe group than in the action group. After job strain exceeded one, workers in the action group were less likely to have MSUE and limited work performance than workers in the safe group. The moderation effect of job control was smaller in the action group than in the safe group. Higher job control may not be critical for workers with high biomechanical exposures, but for workers with low biomechanical exposures.

Keywords: interaction; MSD; disability; occupational stress; job demand; job control; ergonomics; upper limbs

Introduction

Musculoskeletal disorders (MSDs) are major occupational injuries and illnesses resulting in lost work productivity, sick leave, and early exit from work (National Research Council & Institute of Medicine, 2001). Work-related musculoskeletal disorders (WMSDs) are characterized 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 Labour Statistics defines a WMSD case as when a work-related event or exposure led to a bodily reaction (e.g., bending, climbing, crawling, reaching, and twisting), overexertion, or repetitive motion, but this definition does not include disorders caused by slips, trips, falls, or similar incidents. The U.S. rate of WMSDs from overexertion and bodily reaction was 32 cases per 10,000 full-time workers in 2017 and accounted for 32% of days-away-from-work cases in 2017 in private industry (U.S. Bureau of Labor Statistics, 2018). In addition, the Washington State Department of Labour and Industries (2018) reported healthcare and the manufacturing work settings were at high risk for all WMSDs and hand/wrist WMSDs, respectively

Biomechanical job factors (work posture, force exertion, and repetition) and psychosocial job factors (high job demand, low job control, and high job strain) have consistently been considered to be two major risk factors of WMSDs in previous studies (Bernard et al., 1997; Burton, Kendall, Pearce, Birrell, & Bainbridge, 2008; Da Costa & Vieira, 2010; National Research Council & Institute of Medicine, 2001). Emerging studies have examined the interaction between biomechanical and psychosocial factors on MSDs. Studies have indicated that biomechanical 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, De Looze, De Graaff, & Van Dieën, 2004); the combined risk of high biomechanical and psychosocial hazards was greater than the sum of these two hazards, due to their interaction.

A preponderance of studies have supported that an excessive risk of MSDs is attributable to the interactions between biomechanical and psychosocial factors. For example, several cross-sectional studies have shown that workers exposed to both high biomechanical and high psychosocial factors are more likely to have lower back pain (J. J. Devereux, Buckle, & Vlachonikolis, 1999), neck and upper-limb disorders (Devereux, J J, Vlachonikolis, I G, Buckle, 2002; Widanarko, Legg, Devereux, & Stevenson, 2015b), and reduced activities and increased absenteeism (Widanarko, Legg, Devereux, & Stevenson, 2015a). Additionally, cohort studies have shown interaction effects on new episodes of neck and upper extremity pain among white- and blue-collar workers (J. Devereux, Rydstedt, Kelly, Weston, & Buckle, 2004), on quality of life among gas and electrical workers (Sabbath et al., 2013), and on the presence of neck and shoulder pain among coal miners (Widanarko et al., 2015a). In the U.S., Vandergrift and collegeus (2012) showed a three-way interaction among biomechanical factors, job control, and job demand in incidents of lower back pain among automobile manufacturing workers. On the contrary, a few studies did not find similar interaction effects (Harris-Adamson et al., 2016; Pereira, 2009; Prakash et al., 2017).

Except for a study by Harris-Adamson and colleagues (2016), all of the aforementioned studies measured biomechanical factors through self-report, which is subject to information bias. Investigating the interaction between objectively measured biomechanical demands and psychosocial job strain may provide more valid evidence on MSDs. The purpose of this study is to examine the interactions between biomechanical demand and psychosocial job strain on musculoskeletal symptoms in the upper extremities (MSUE) and the resulting limitations on work performance. The specific hypotheses are as follows:

- H1: There is an interaction between biomechanical demand and psychosocial job strain on MSUE
- H2: There is an interaction between biomechanical demand and psychosocial job strain on limited 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 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. Ergonomists from SHARP contacted facilities with at least 20 employees who were exposed to varied biomechanical exposures; to be included in the study, each facility had to have at least three exposure categories (two levels of hand force [high/low] by three levels of repetition [high/medium/low]), based on rough walk-through assessments. They 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 biomechanical exposures. The original SHARP study investigating occupational factors for MSDs in the upper extremities involved 1) an individual biomechanical 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, but due to an economic recession resulting in layoffs and terminations, the sample size decreased to 467 on 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=10 one year later, n=15 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.

Measurement

Biomechanical job factors

Biomechanical 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 in follow-up visits. 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 videotaping participants from two angles for synchronized viewing of them completing job tasks and analyzed in a laboratory using the Multimedia Video Task Analysis software (Yen & 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 minimize bias. Further details about the data collection, processing, and analysis have been reported elsewhere (Bao, Howard, Spielholz, & Silverstein, 2006; Bao, Spielholz, Howard, & Silverstein, 2006). To estimate a composite biomechanical demand, two widely used ergonomic risk assessment tools for upper extremities in both practice and research, Strain Index and Threshold Limit Value, were applied (Garg et al., 2012).

Strain Index (SI). SI (Steven, Moore, & Garg, 1995) is a distal upper extremity biomechanical 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 (Stephen Bao, Spielholz, Howard, & Silverstein, 2009). SI scores ranged from .0625 to 1053, and a higher SI indicated strenuous biomechanical exposure. Participants were categorized into three groups based on SI scores: Safe (SI≤3), Action (3<SI≤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 normalized peak hand force TLV and the action limit (AL) were calculated. The measured peak forces of the workers were compared to these calculated normalized peak hand force thresholds of TLV and AL and were categorized into the safe (under the AL), action (between AL and TLV), or hazardous (above TLV) groups.

Psychosocial job strain

An adapted version of the Job Content Questionnaire (JCQ; Karasek & Theorell, 1990) was used to assess psychosocial job demand through five items (working fast, working hard, no excessive work, enough time, hectic[1]) and job control through nine items (learning new things, engaging in repetitive work, being creative, having a high level of skill, variety, receiving training[1] [2], having little freedom to decide, a lot to say, taking a break[1] [2]) (Silverstein et al., 2006). Three revised questions were used to replace

[1] This is a revised item.

"conflict demand" in the psychological job demand and "develop ability" and "allow decision" in the job control. The total score ranged from 12 to 48 for psychosocial job demand and from 24 to 96 for job control. A job-strain quotient term was used for creating a continuous psychosocial job strain, which was calculated by doubling psychosocial job demand and dividing by job control (Landsbergis et al., 2015; Landsbergis, Schnall, Warren, Pickering, & Schwartz, 1994). The psychosocial job strain ranged from 0.25 to 4.

MSUE and limited work performance

MSUE and work performance were measured by the eleven-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 outcome measures for patients with MSUE by assessing symptoms and functional status (Beaton, Davis, Hudak, & Mcconnell, 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, Silverstein, Wickizer, Martin, & Kaufman, 2007), and was sensitive to the occurrence or recovery of MSUE (Fan, Smith, & 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 were 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 item] -1×25) 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 utilized 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 (thyroid disease, diabetes mellitus, and rheumatoid arthritis), and prior diagnosis of MSDs in upper extremities were also collected.

Data Analysis

Descriptive statistics were used to characterize the study sample at baseline, one year later, and two years later. Item non-responses for the psychosocial job questionnaire (job demand, job control, job security, co-worker support) were treated with multiple imputation using predictive mean matching. This imputation was done using the *MICE* package (van Buuren & 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 analyze a data structure where observations (level 1) were nested within a worker (level 2) in a company (level 3). There was an effect of an individual nested in a company 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 conditions, including thyroid disease, diabetes mellitus, and rheumatoid arthritis) and occupational characteristics (years in current company, job security (high or low using a median) and co-worker support (high or low using a median). 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 simple main model of biomechanical demand and psychosocial job strain and an interaction model that added the interaction term of biomechanical demand and psychosocial job strain to the simple model. Since these two models were nested, likelihood ratio tests were carried out to examine the effect of the interaction between biomechanical demand and psychosocial 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% confidence intervals. Additionally, to understand how psychosocial job demand and job control contribute to the interaction, a sensitivity analysis was conducted by treating job demand and job control as separate exposure variables. The effect of the interactions on MSUE and limited work performance were investigated via likelihood ratio tests 1) between biomechanical demand and psychosocial job demand, 2) between biomechanical demand and job control, and 3) among biomechanical demand, psychosocial job demand, and job control. This was done with the *lme4* package (Bates, Mächler, Bolker, & Walker, 2015) in R software.

Results

The majority of participants (86.5%) worked in the manufacturing sector (electronics, medical or exercise equipment, windows, kitchen cabinets, wood mills). Demographic characteristics at each time point are presented in Table 4.1. 713 participants with 1450 observations (n=669 at baseline, n=428 one year later, n=353 two years later) over the course of two years 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. The mean age of the participants and the years employed at the current company at baseline were 39.4 (SD: 10.8) and 5.7 (SD: 6.9) years, respectively. Nine percent of subjects had comorbidities, such as thyroid disease, diabetes mellitus, and rheumatoid arthritis. According to the SI, although participants were equally distributed across the three different biomechanical job risk categories, slightly more were grouped in the safe 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 data collection waves, except for MSD diagnosis and psychosocial job strain. The prevalence of MSDs in upper extremities, such as carpal tunnel syndrome, thoracic outlet syndrome, hand/wrist tendinitis, epicondylitis, trigger finger, rotator cuff syndrome, and ruptured disc in neck increased from the baseline to the follow-ups (23% at baseline, 29% one year later, and 29% two years later, p=.04). The psychosocial job strain's mean at each time point was 1.08 (SD: 0.27, range: 0.43-2.44) at baseline, 1.04 (SD: 0.23, range: 0.23-2.47) one year later, and 1.03 (SD: 0.23, range: .23-2.33) two years later, showing a decrease from the baseline to the last follow-up visit (p=.002).

[Insert Table 4.1 about here]

The effect of biomechanical demand and psychosocial job strain on MSUE

Table 2 displays the regression models for the outcome MSUE, including estimations of the interaction between biomechanical demand and psychosocial job strain. To determine the level of biomechanical demand, SI (model 1 and model 2) and TLV for HA (model 3 and model 4) were used in the analysis. Psychosocial job strain showed a statistically significant effect on MSUE across all models after adjusting for gender, age, education level, and smoking status. However, the effects of biomechanical demand on MSUE were not statistically significant except in model 4.

Likelihood ratio tests were carried out to assess interactions between the SI and psychosocial job strain (model 1 vs. model 2) and between TLV for HA and psychosocial job strain (model 3 vs. model 4). A statistically significant interaction was observed between TLV for HA and psychosocial job strain (p=.01), though not between the SI and psychosocial job strain (p=.9). Model 4 indicated that the coefficient of the interaction between the action group of TLV for HA and psychosocial job strain was -9.3 (95% CI: -16.6, -1.7), while the coefficients of psychosocial job strain and the action group were 9.5 (95% CI: 4.9, 14.1) and 10.6 (95% CI: 2.4, 18.7), respectively. Figure 4.1 displays the predicted effects of the interaction in model 4. As psychosocial job strain increases, the degree of MSUE is predicted to remain consistent in the action group but to be higher in the safe group.

[Insert Table 4.2 about here]

[Insert Figure 4.1 about here]

The effect of biomechanical demand and psychosocial job strain on limited work performance

Table 4.3 displays the regression models for the outcome limited work performance, including estimates of the interaction between biomechanical demand and psychosocial job strain. To determine the level of biomechanical factors, the SI (model 5 and model 6) and TLV for HA (model 7 and model 8) were used in analysis. Psychosocial job strain showed a statistically significant effect on limited work performance across all four models after adjusting for gender, age, level of co-worker support, and level of job security. However, the effects of biomechanical demand on limited work performance were only statistically significant in models 6 and 8.

Likelihood ratio tests were conducted to assess interactions between the SI and psychosocial job strain on limited work performance (models 5 and 6), and between TLV for HA and psychosocial job strain on limited work performance (models 7 and 8). A statistically significant interaction was observed between the SI and psychosocial job strain on limited work performance (p=.04) and between TLV for HA and psychosocial job strain on limited work performance (p=.008). Model 6 indicated that the coefficient of the interaction between of the SI and psychosocial job strain in the action group was -10.2 (95% CI: -17.7, -2.6), while the coefficients of psychosocial job strain and the action group were 13.7 (95% CI:8.1, 19.3) and 1.7(95 %CI: 3.1, 19.8), respectively.

Similarly, model 8 indicated that the coefficient of the interaction between the action group of TLV for HA and psychosocial job strain was -11.4 (95% CI: -19.1, -3.6), while the coefficients of psychosocial job strain and the action group were 12.4 (95% CI: 7.3, 16.9) and 12.2 (95% CI: 4.3, 20.9), respectively. Figure 2 displays the predicted effects of the interaction in models 6 and 8. As psychosocial job strain increases, the degree of limited work performance was predicted to remain consistent in the action group of TLV for HA but to be higher in the safe group (Figure 4.2). A similar trend was observed in model 8 in which the degree of limited work performance was predicted to be smaller in the action group for the SI compared to the safe group for SI (Figure 4.2).

[Insert Table 4.3 about here]

[Insert Figure 4.2 about here]

Sensitivity analysis: interaction among psychosocial job demand, job control, and biomechanical demand

Sensitivity analysis was done using psychosocial job demand and job control as separate exposures instead of psychosocial job strain in models 4, 6, and 8. Table 4.4 displays the sensitivity analysis for the outcome MSUE, including estimates of the interaction among biomechanical demand (TLV for HA), psychosocial job demand, and job control. Likelihood ratio tests were conducted to assess interactions between TLV for HA and psychosocial job demand (models 9 and 10), between TLV for HA and job control (models 9 and 11), and among TLV for HA, psychosocial job demand and job control (models 11and 12). Results showed that the interaction effect between TLV for HA and job control on MSUE was significant after adjusting for psychosocial job demand and confounders. Figure 4.3 displays the predicted effects of the interaction in model 11. As job control increases, the degree of MSUE was predicted to be higher in the action group for TLV for HA but to be lower in the safe group for TLV for HA.

[Insert Table 4.4, Figure 4.3 about here]

Tables 4.5 and 4.6 describe the sensitivity analysis for the outcome limited work performance, including estimates of the interaction among biomechanical demand (TLV for HA and the SI), psychosocial job demand, and job control. A similar procedure was done above. Results showed that the effect of interactions between biomechanical demand (for both the SI and TLV for HA) and job control on limited work performance was significant after adjusting for psychosocial job demand and confounders. Figure 4.4 displays the predicted effects of the interaction in model 15 (SI and job control) and model 19 (TLV for HA and job control). As job control increases, the degree of limited work performance was predicted to be higher in the action group (for both the SI and TLV for HA) but to be lower in the safe group.

[Insert Table 4.5, Table 4.6, and Figure 4.4 about here]

Discussion

This study investigated the interaction between biomechanical demand and psychosocial job strain on MSUE and limited work performance. Our findings indicate the impact of psychosocial job strain on limited work performance was smaller in the action group compared to the safe group. The main reason for these interactions was due to the role of job control in psychosocial job strain. As job control becomes greater, the predicted limited work performance was higher in the action group, but lower in the safe group. Similar results were observed for MSUE, but statistically significant biomechanical exposure was only observed when level of biomechanical demand was measured by TLV for HA, not by the SI.

Our findings show observable interactions were between psychosocial job strain and biomechanical demand as well as between job control and biomechanical demand.

An interaction between psychosocial job demand and biomechanical demand was not found in this study. Prior studies indicated that the significant synergistic interaction effect on MSDs was observed only between self-reported biomechanical factors and psychosocial job strain (Devereux, Vlachonikolis, Buckle, 2002; JDevereux et al., 1999; Devereux et al., 2004; Sabbath et al., 2013; Widanarko et al., 2015b, 2015a), but not between objectively measured biomechanical factors and psychosocial job strain (Harris-Adamson et al., 2016). These previous studies used job strain as a quadrant-term and classified individuals as experiencing high job strain when they reported above median scores for psychosocial job demand and below median scores for job control. While this approach has been widely used, it has shown the lowest accuracy in predicting health outcomes compared to other formulations of psychosocial job strain (the subtraction, logarithm, and quotient approaches) (Courvoisier & Perneger, 2010).

A few prior studies have examined the interaction between job control and biomechanical factors on MSDs with varying findings. The buffering effect of job control on musculoskeletal symptoms was not apparent in high biomechanical exposures among nursing home workers (Hollmann, Heuer, & Schmidt, 2001). In contrast, MacDonald and colleagues (2001) found a strong negative relationship between job control and biomechanical exposure of the upper extremities among blue- and white-collar workers in manufacturing companies. Even though it is not significant, job control attenuated slightly the estimate of forceful hand exertion on the rate of carpal tunnel syndromes among workers from six states in the United States (Harris-Adamson et al., 2016). Even fewer studies have considered the effect psychosocial job demand in conjunction with job control and biomechanical demand on MSDs. For example, a study on three-way interactions found that high psychosocial demand related to low back pain occurrence only in cases of low job control and high biomechanical demand among automobile manufacturing workers (Vandergrift et al., 2012).

Since biomechanical demands and psychosocial job strain can be correlated, it is difficult to estimate their interaction. High biomechanical jobs structurally involve high psychosocial job demand and low job control (Kausto et al., 2011). This trend is evident among blue-collar workers, where high correlations can be observed between psychosocial job strain and repetitive work in the study by MacDonald and colleagues (2001). In addition, items from the JCQ questionnaire about working hard or working fast can be perceived as biomechanical efforts by workers (Choi et al., 2012; Punnett, 2014).

In this analysis, why the action group showed lower MSUE and limited work performance with higher job strain compared to the safe group could be due to the healthy worker effect. Those who already suffered from MSDs might have left the studied workplace or changed jobs to ones with lower biomechanical workloads. It is plausible that healthy people make up more of the hazardous- or action-level groups, while people with MSDs may have moved to the safe job group (i.e., for light duty jobs), where their disabilities have not fully recovered. It may not be feasible to examine MSD disabilities among currently employed healthy workers, and, to our knowledge, most work disability studies have been conducted among patients who are on sick leave. Also, it is worth noting that not all workers with MSDs take sick leave or absences. The majority of workers continue working while experiencing symptoms (Herr et al., 2015; Silverstein et al., 2006; Walker-Bone, Reading, Coggon, Cooper, & Palmer, 2004).

This study should be viewed in light of some limitations. First, there were many lost follow-up interviews and assessments due to an economic recession that occurred during the data collection period. Despite the possibility that workers with MSDs may be more likely to be laid off, there is no evidence to support that possibility in this study. 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 from 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. Third, while biomechanical 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. Fourth, the SI can measure biomechanical demand on the distal upper extremities, but it is limited in its ability to estimate demand on shoulders. 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, & Kapellusch, 2017).

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 biomechanical and psychosocial hazards on MSD symptoms and work performance is critical as it can help prevent the possibility of underestimating the combined effects of occupational hazards on MSDs. This knowledge can also inform more comprehensive intervention strategies that combine biomechanical and psychosocial approaches. While this study did not provide sufficient evidence to suggest the effect of a synergistic interaction between biomechanical demand and psychosocial job strain on MSUE and work performance, it did provide evidence suggesting the impacts of psychosocial job strain and job control on MSUE and work performance are smaller in the action level of biomechanical demand jobs compared to the safe level of biomechanical demand jobs. This implies that ergonomic engineering is more important than higher job control among workers with high biomechanical demand, while higher job control is more important among workers with low biomechanical demand. Further studies are needed to elucidate how the interactions between biomechanical and psychosocial hazards affect MSDs.

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Table 4.1. Descriptive statistics of the participants, cohort study, 2001-2004

	Baseline (N=669)		Wave 2 (N=428)		Wave 3 (N=353)		P-value
	N (%)	Mean (SD)	N (%)	Mean (SD)	N (%)	Mean (SD)	
Male	348 (52)		214 (50)		164 (46)		.240
Age		39.4 (10.8)		41.2(10.8)		43.2 (10.3)	.001
Race/Ethnicity							.942
White	402 (60)		258 (60)		213 (60)		
Asian	121 (18)		82 (19)		69 (20)		
Hispanic	84 (13)		52 (12)		46 (13)		
Others	62 (9)		36 (8)		25 (7)		
Education							.947
Less than high school	113 (17)		69 (16)		51 (14)		
High school graduate	494 (48)		205 (48)		167 (47)		
Some college	175 (26)		110 (26)		99 (28)		
≥Bachelor	62 (9)		44 (10)		36 (10)		
Smoking status							.575
Non-smoker	329 (49)		197 (46)		168 (48)		
Ex-smoker	141 (21)		99 (23)		88 (25)		
Current smoker	199 (30)		132 (31)		97 (27)		
Tenure (in years)		5.7 (6.9)		7.2 (7.2)		8.5 (7.6)	.001
Comorbidity [1]	62 (9)		40 (9)		33 (9)		.999
MSDs in upper extremities [2]	152 (23)		122 (29)		101 (29)		.041
Psychosocial job strain		1.08 (0.27)		1.04 (0.23)		1.03 (0.23)	.002
High co-worker support	380 (57)		235 (55)		191 (54)		.672
High job security	457 (68)		278 (65)		257 (73)		.063
Biomechanical job demand							
The Strain Index (SI)							.109

[1] Thyroid disease, diabetes mellitus, and rheumatoid arthritis
[2] Musculoskeletal disorders in upper extremities including carpal tunnel syndrome, thoracic outlet syndrome, hand/wrist tendinitis, epicondylitis, trigger finger, rotator cuff syndrome, and ruptured disc in neck

- Safe (SI≤ 3)	224 (33)	155 (36)	148 (42)	
- Action (3<SI≤ 7)	198 (30)	127 (30)	96 (27)	
- Hazardous (SI)7)	247 (37)	146 (34)	109 (31)	
Threshold Limit Value for hand activity				.431
- Safe	273 (41)	178 (42)	159 (45)	
- Action	224 (33)	155 (36)	117 (33)	
- Hazardous	172 (26)	95 (22)	77 (22)	
Upper extremities symptom score [3]	11.67 (15.24)	10.74 (15.40)	10.96 (15.99)	.578
Limited work performance score [4]	8.17 (14.87)	6.94 (14.61)	6.91 (14.61)	.285

[3] This was measured by the QuickDASH.
[4] This was measured by the QuickDASH work module.

Table 4.2. Results of multilevel linear regression for upper extremities symptom score (range 0-100; based on QuickDASH; n=1450 observations across 713 individuals in 12 companies) [1]

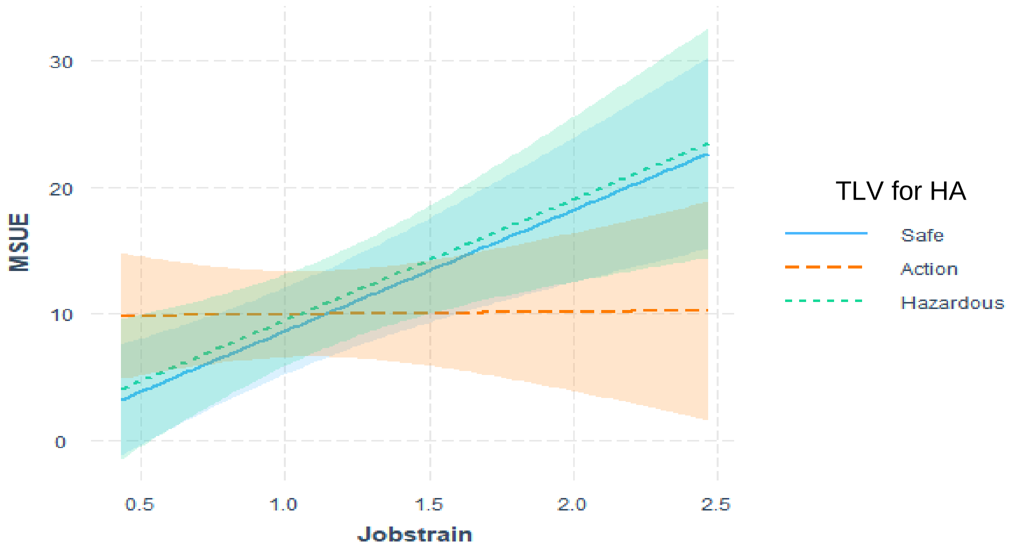
Fixed Effects	Model1 Strain Index	Model 2 Strain Index	Model 3 TLV for HA [2]	Model 4 TLV for HA
	Coeff (95%CI)	*Coeff (95%CI)*	*Coeff (95%CI)*	*Coeff (95%CI)*
Intercept	-2.0 (-6.7, 2.4)	-3.1 (-10.0, 3.3)	-1.9 (-6.6, 3.2)	-4.7 (-10.9, 0.8)
Gender				
Male	-	-	-	-
Female	7.7 (5.7, 9.9)	7.5 (5.8, 9.8)	7.8 (5.8, 9.9)	7.7 (5.8,9.8)
Age				
18-33	-	-	-	-
34-41	1.7 (-0.9, 4.3)	1.8 (-1.0, 4.3)	1.7 (-1.0, 4.3)	1.8 (-0.6, 4.4)
42-49	4.3 (1.8, 6.6)	4.3 (1.9, 7.0)	4.3 (1.7, 6.9)	4.1 (1.6, 6.6)
50-67	7.8 (5.2, 10.4)	7.9 (5.3, 10.6)	7.8 (4.8, 10.4)	7.8 (5.0, 10.3)
Education				
Less than high school	-	-	-	-
High school graduate	-3.0 (-6.1, -0.1)	-3.0 (-5.7, -0.1)	-3.1 (-5.8, -0.4)	-2.9 (-5.8, -0.2)
Some college	-0.9 (-4.2, 2.4)	-0.9 (-3.9, 2.2)	-1.0 (-3.9, 2.0)	-0.7 (-3.7, 2.3)
≥Bachelor	-4.6 (-9.0, -0.8)	-4.5 (-8.6, -0.1)	-4.6 (-8.5, -0.5)	-4.3 (-8.3, -0.3)
Smoking status				
Non-smoker	-			
Ex-smoker	2.4 (0.3,4.5)	2.3 (0.2, 4.4)	2.4 (0.2, 4.4)	2.3 (0.1, 4.4)
Current smoker	2.1(-0.001,4.2)	2.0 (-0.1, 4.1)	2.0 (0.01, 4.1)	1.9 (-0.3, 4.1)
Psychosocial job strain	6.8 (3.7, 10.0)	7.8 (2.6, 13.2)	6.7 (3.6, 9.8)	9.5 (4.9, 14.1)
Biomechanical job demand				
Safe	-	-	-	-
Action	1.0 (-1.3.3.0)	4.7 (-3.3, 12.7)	0.6 (-1.5, 2.8)	10.6 (2.4, 18.7)
Hazardous	0.8 (-1.5, 3.0)	0.6 (-7.3, 9.0)	1.2 (-1.0, 3.5)	0.9 (-7.3, 9.8)
Interaction				

[1] To identify a parsimonious model, the confounders (race/ethnicity, comorbid medical condition, tenure, job security, and co-worker support) that did not provide significant impact on model fit were deleted.

[2] TLV for HA: Threshold Limit Value for hand activity

Safe × Psychosocial job strain		-		-
Action × Psychosocial job strain		-3.5 (-10.8, 4.0)		-9.3 (-16.6, -1.7)
Hazardous × Psychosocial job strain		0.1 (-7.6, 7.4)		-0.02 (-7.8, 7.1)
Random effects (intercepts)				
Between individuals in a company	105.6	105.2	105.8	105.7
Between companies	4.2	4.2	4.2	4.1
Residual	102.0	102.1	101.9	101.2
Model Information				
AIC	11641	11644	11641	11638
BIC	11726	11739	11726	11733
Loglikelihood	-5805	-5804	-5805	-5801

Figure 4.1.Effects of interaction between psychosocial job strain and biomechanical job demand (TLV for HA) on upper extremities symptom score [1]



[1] TLV for HA: Threshold Limit value for hand activity; Shaded areas indicate 95% confidence intervals

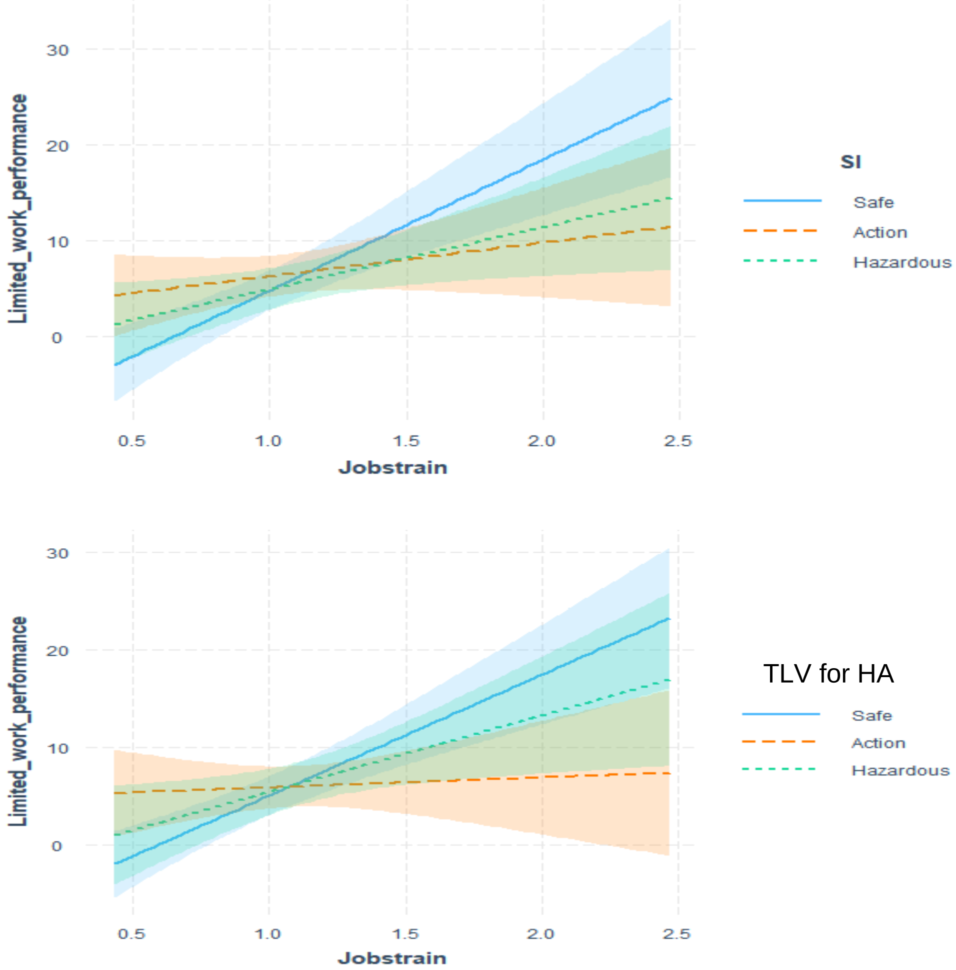
Table 4.3. Results of multilevel linear regression for limited work performance score (range 0-100; based on QuickDASH-work module; n=1450 observations across 713 individuals in 13 companies) [1]

Fixed Effects	Model 5 Strain Index	Model 6 Strain Index	Model 7 TLV for HA [2]	Model 8 TLV for HA
	Coeff (95%CI)	*Coeff (95%CI)*	*Coeff (95%CI)*	*Coeff (95%CI)*
Intercept	-6.4 (-10.2, -2.4)	-12.0 (-17.5, -5.9)	-4.8 (-9.1, -0.3)	-9.3(-14.6, -3.6)
Gender				
Male	-	-	-	-
Female	4.0 (2.0, 5.7)	4.0 (2.2, 5.8)	4.1 (2.3, 6.0)	4.0 (2.3, 5.8)
Age				
18-33	-	-	-	-
34-41	1.1 (-1.30, 3.51)	1.2 (-1.3, 3.8)	1.0 (-1.5, 3.4)	1.1 (-1.4, 3.5)
42-49	2.7 (0.3, 5.0)	28 (0.4, 4.9)	2.6 (0.3, 5.0)	2.5 (0.2, 4.7)
50-67	4.8 (2.4, 7.3)	4.8 (2.4, 7.3)	4.8 (2.4, 7.1)	4.8 (2.3,7.1)
Co-worker support				
High	-	-	-	-
Low	1.6 (0.1, 3.1)	1.5 (0.1, 3.2)	1.6 (0.04, 3.3)	1.61 (0.1.3.3)
Job Security				
High	-	-	-	-
Low	1.3 (-0.4, 3.1)	1.3 (-0.4, 4.9)	-1.4 (-3.0, 0.4)	-1.3 (-2.8,0.4)
Psychosocial job strain	8.0 (4.7, 11.3)	13.7 (8.1, 19.3)	8.0 (4.6, 11.5)	12.4 (7.3, 16.9)
Biomechanical demand				
Safe	-	-	-	-
Action	1.1 (-0.9, 3.2)	11.7 (3.1, 19.8)	0.19 (-1.7, 2.1)	12.2 (4.3,20.9)
Hazardous	-0.01 (-1.9,1.9)	7.4 (-1.2, 15.8)	0.4 (-1.7, 2.5)	5.00 (-4.5, 13.8)
Interactions				
Safe × Psychosocial job strain		-		-
Action × Psychosocial job strain		-10.2 (-17.7, -2.6)		-11.4 (-19.1, -3.6)
Hazardous × Psychosocial job strain		-7.2 (-14.9, 0.6)		-4.5(-12.7, 3.9)
Random effects (intercepts)				

[1] To identify a parsimonious model, the confounders (education, race/ethnicity, comorbid medical condition, and tenure) that did not provide significant impact on model fit were deleted.
[2] TLV for HA: Threshold Limit Value for hand activity

Between individuals in a company	44.2	43.3	44.4	43.9
Between companis	1.2	1.1	1.2	1.2
Residual	161.5	161.3	161.6	160.8
Model Information				
AIC	11826	11823	11828	11823
BIC	11895	11902	11896	11902
Loglikelihood	-5900	-5897	-5901	-5896

Figure 4.2. Effects of interaction between psychosocial job strain and biomechanical demand (Top: Strain Index, Bottom: TLV for HA [1]) on limited work performance score



[1] TLV for HA: Threshold Limit Value for hand activity; Shaded areas indicate 95% confidence intervals.

Table 4.4. Results of the interaction among psychosocial job demand, job control, and biomechanical demand (TLV for HA) on upper extremities symptom score (range 0-100; based on QuickDASH-work module; n=1450 observations across 713 individuals in 13 companies) [1]

Fixed Effects	Model 9 TLV for HA	Model 10 TLV for HA	Model 11 TLV for HA [2]	Model 12 TLV for HA
	Coeff (95%CI)	*Coeff (95%CI)*	*Coeff (95%CI)*	*Coeff (95%CI)*
Psychosocial job demand	0.3 (0.2 0.5)	0.3 (0.2, 0.7)	0.3 (0.2, 0.5)	0.9 (-1.23, 1.36)
Job control	-0.2 (-0.3, -0.003)	-0.3 (-3.6, -0.002)	-0.3 (-0.6, -0.1)	0.1 (-1.87.0,0.68)
Biomechanical job demand				
Safe	-	-	-	-
Action	0.6 (-1.5, 2.7)	5.7 (-4.2, 22.1)	-14.3 (-2.7, -2.3)	62.6 (-9.0, 65.0)
Hazardous	1.1 (-1.2, 3.4)	-0.2 (-15.2, 14.6)	-1.2 (-1.5, 12.0)	-71.6 (-1.9, -12.9)
Interactions				
Safe × Psychosocial job demand		-		-
Action × Psychosocial job demand		-0.2 (-0.7, 0.1)		-2.4 (-2.3, 2.3)
Hazardous × Psychosocial job demand		-0.001(-0.4, 0.5)		1.8 (0.2, 5.5)
Safe × Job control			-	-
Action × Job control			0.5 (0.1,0.9)	-0.02 (-0.002, 0.1)

[1] All models were adjusted for gender, age, education, and smoking status. To identify a parsimonious model, the other confounders (race/ethnicity, comorbid medical condition, tenure, job security, and co-worker support) that did not provide significant impact on model fit were deleted.
[2] TLV for HA: Threshold Limit Value for hand activity

Hazardous × Job control			0.1 (-3.8,0.5)	2.4 (0.2, 5.5)
Psychosocial job demand × Job control				-0.02 (-0.03, 0.05)
Safe × Psychosocial job demand × Job control				-
Action × Psychosocial job demand × Job control				0.1 (-0.01,0.1)
Hazardous × Psychosocial job demand × Job control				-0.1 (-0.01, -0.01)
Random effects (intercepts)				
Between individuals in a company	104.7	43.9	104.0	43.4
Between companies	4.5	1.5	4.8	1.5
Residual	102.1	161.3	101.7	159.8
Model Information				
AIC	11640	11832	11637	11828
BIC	11730	11921	11738	11944
Loglikelihood	-5803	-5899	-5800	-5892

Table 5. Results of the interaction among psychosocial job demand, job control, and biomechanical demand (Strain Index) on limited work performance score (range 0-100; based on QuickDASH-work module; n=1450 observations across 713 individuals in 12 companies) [1]

Fixed Effects	Model 13 Strain Index	Model 14 Strain Index	Model 15 Strain Index	Model 16 Strain Index
	Coeff (95%CI)	*Coeff (95%CI)*	*Coeff (95%CI)*	*Coeff (95%CI)*
Psychosocial job demand	0.3 (0.2,0.5)	0.4 (0.1,0.8)	0.3 (0.1, 0.5)	1.5 (-0.2, 3.2)
Job control	-0.3 (-0.5, -0.1)	-0.3(-0.5, -0.1)	-0.5 (-0.8, -0.2)	0.6 (-1.0, 2,3)
Biomechanical factor				
Safe	-	-	-	-
Action	1.0 (-0.9, 3.2)	5.3 (3.1, 19.8)	-15.6 (-1.7, 2.1)	71.1(4.3,20.9)
Hazardous	-0.1 (-1.9,1.9)	5.5 (-1.2, 15.8)	-9.5 (-1.7, 2.5)	-18.0 (-4.5, 13.8)
Interactions				
Safe × Psychosocial job demand		-		-
Action × Psychosocial job demand		-0.1 (-17.7, -2.6)		-2.7 (-19.1, -3.6)
Hazardous × Psychosocial job demand		-0.2 (-14.9, 0.6)		0.2 (-12.7, 3.9)
Safe × Job control			-	-
Action × Job control			0.5 (0.1,0.9)	-2.2 (-4.8, 0.3)

[1] All models were adjusted for gender, age, level of co-worker support, and level of job security. To identify a parsimonious model, the other confounders (education, race/ethnicity, comorbid medical condition, and tenure) that did not provide significant impact on model fit were deleted.

Hazardous × Job control			0.3 (-0.1, 0.7)	0.8 (-2.0, 3.5)
Psychosocial job demand × Job control				-0.03(-0.1, 0.01)
Safe × Psychosocial job demand × Job control				-
Action × Psychosocial job demand × Job control				0.09 (0.002, 0.16)
Hazardous × Psychosocial job demand × Job control				-0.01(-0.01, 0.1)
Random effects (intercepts)				
Between individuals in a company	44.1	44.1	42.5	41.15
Between companies	1.4	1.3	1.4	1.4
Residual	161.5	161.4	161.7	161.7
Model Information				
AIC	11828	11831	11825	11827
BIC	11902	11916	11909	11938
Loglikelihood	-5900	-5900	-5896	-5893

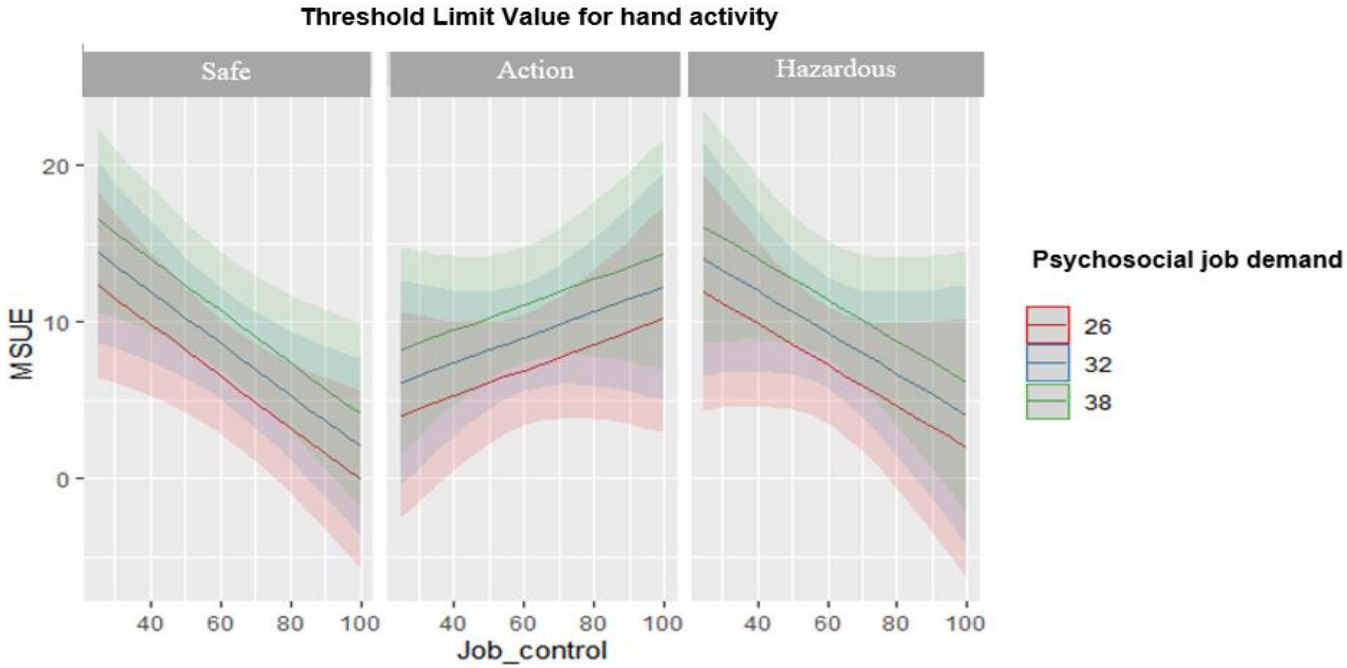
Table 4.5. Results of the interaction among psychosocial job demand, job control, and biomechanical demand (TLV for HA [1]) on limited work performance score (range 0-100; based on QuickDASH-work module; n=1450 observations across 713 individuals in 12 companies) [2]

Fixed Effects	Model 17 TLV for HA	Model 18 TLV for HA	Model 19 TLV for HA	Model 20 TLV for HA
	Coeff (95%CI)	*Coeff (95%CI)*	*Coeff (95%CI)*	*Coeff (95%CI)*
Psychosocial job demand	0.3 (0.1,0.5)	0.4 (0.1, 0.7)	0.3 (0.1, 0.5)	1.5 (-0.5, 2.2)
Job control	-0.3 (-0.5, -0.1)	-0.3 (-0.4, -0.1)	-0.5 (-0.7,-0.3)	0.6 (-0.1, 1.5)
Biomechanical factor				
Safe	-	-	-	-
Action	1.0 (-0.9, 3.2)	5.3 (3.1, 19.8)	-15.6 (-1.7, 2.1)	71.1(4.3,20.9)
Hazardous	-0.1 (-1.9,1.9)	5.5 (-1.2, 15.8)	-9.5 (-1.7, 2.5)	-18.0 (-4.5, 13.8)
Interactions				
Safe × Psychosocial job demand		-		-
Action × Psychosocial job demand		-0.1 (-17.7, -2.6)		-2.7 (-19.1, -3.6)
Hazardous × Psychosocial job demand		-0.2 (-14.9, 0.6)		0.2 (-12.7, 3.9)
Safe × Job control			-	-
Action × Job control			0.5 (0.2, 1.0)	-2.2 (-0.1, 0.02)

[1] TLV for HA: Threshold Limit Value for hand activity
[2] All models were adjusted for gender, age, level of co-worker support, and level of job security. To identify a parsimonious model, the other confounders (education, race/ethnicity, comorbid medical condition, and tenure) that did not provide significant impact on model fit were deleted.

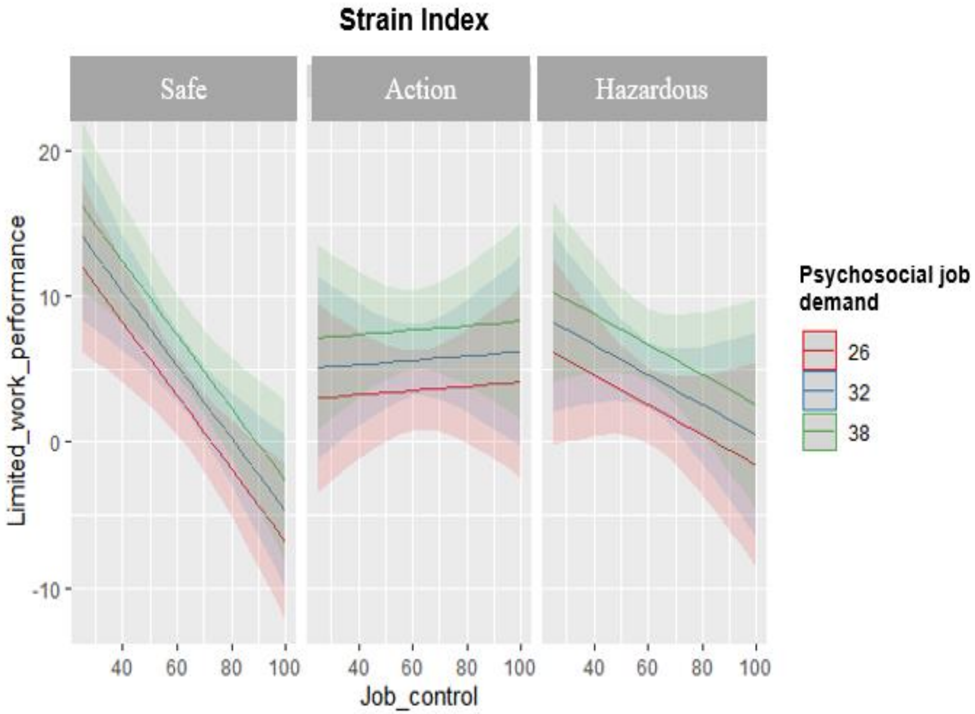
Hazardous × Job control			0.3 (-0.2, 0.8)	0.8 (-0.9, 5.5)
Psychosocial job demand × Job control				-0.03 (-0.1, 0.02)
Safe × Psychosocial job demand × Job control				-
Action × Psychosocial job demand × Job control				0.09 (-0.01,0.2)
Hazardous × Psychosocial job demand × Job control				-0.01 (-0.2, 0.04)
Random effects (intercepts)				
Between individuals in a company	44.1	44.1	42.5	41.15
Between companies	1.4	1.3	1.4	1.4
Residual	161.5	161.4	161.7	161.7
Model Information				
AIC	11828	11831	11825	11827
BIC	11902	11916	11909	11938
Loglikelihood	-5900	-5900	-5896	-5893

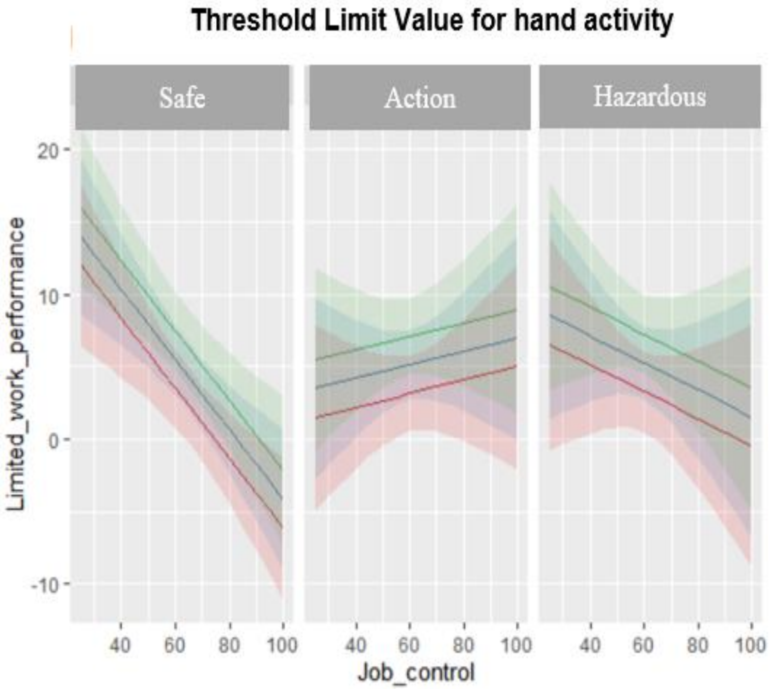
Figure 4.3. Effects of interaction among psychosocial job demand, job control, and biomechanical job demand (TLV for HA) on upper extremities symptom score (MSUE) [1]



[1] Shaded areas indicate 95% confidence intervals

Figure 4.4. Effects of interaction among psychosocial job demand, job control, and biomechanical job demand (left: Strain Index, right: Threshold Limit Value for hand activity) on limited work performance [1]





[1] Shaded areas indicate 95% confidence intervals

Chapter 5. **Conclusions**

This dissertation investigated the relationship between biomechanical demand, psychosocial job factors, MSUE, and work performance among the currently working population. The first study (chapter 2) showed that when workers experience moderate MSP or multisite MSP, they are encouraged to seek help. Initiating early interventions for MSDs is based solely on workers' reports. However, since MSUE is very prevalent and recurrent among the general population, workers may not know the level of MSUE severity that requires medical care or interventions in order to prevent chronic MSDs. When responding to workers' reports of MSP, health professionals and employers can help workers' recovery and prevent work disability by examining their work abilities and/or providing temporary job accommodations. However, the current MSP index considers only sensitivity and specificity and there is no a gold standard test for lost work performance. Future studies are needed to check the consistency of lost work performance by examining performance levels among different populations and using a different work performance scale. Also, a study examining a cut-off point that considers the prevalence of lost work performance among the working population and the cost ratio of false positive and false negative results would be useful in practice.

The aim of the second study (chapter 3) was to examine the moderation effect of psychosocial job resources (coworker support, job security, and job satisfaction) on the path from biomechanical demand to MSUE; the path from psychosocial job strain to MSUE; and the path from MSUE to limited work performance. Job security and job satisfaction showed a buffering effect on the path from MSUE to limited work performance, but coworker support did not. The effect of biomechanical demand on MSUE depended on the level of job security, with a stronger effect of biomechanical demand on MSUE among workers with low job security. The effect of MSUE on work performance depended on the level of job satisfaction, with workers with higher job satisfaction being less likely to experience limited work performance due to MSUE compared to those with low job satisfaction. MSD programs in workplaces and government policies need to include decreasing the hazards of job insecurity as well as prioritizing providing MSD intervention programs for vulnerable populations. The work environment needs to be safe and satisfying to workers with a common level of MSUE. More studies need to be done to determine what factors can increase job satisfaction to enable workers with MSUE to maintain their work performance.

The aim of the third study (chapter 4) was to investigate the interaction between the effects of biomechanical demand and psychosocial job strain on MSUE and work performance. While this study did not provide sufficient evidence to suggest a synergistic interaction between biomechanical demand and psychosocial job strain on MSUE and work performance, it did provide evidence suggesting that the impacts of job strain and job control on MSUE and work performance are smaller in action (middle) levels of biomechanical demand compared to safe levels. Traditionally, having high job control has been considered to decrease stress and negative health impacts. However, this study provided evidence that higher control may not be critical to workers exposed to high biomechanical job demand. This implies that ergonomic engineering should be prioritized over higher job control among workers with high biomechanical demand, while high job control is more important among workers with low biomechanical demand. Further studies are needed to further elucidate the effect of interactions between biomechanical demand and psychosocial hazards on MSDs.

MSDs are one of the major occupational issues in industrialized countries and are a cause of major disability. Due to the multifactorial nature of MSDs—influenced by biomechanical, psychosocial, organizational, and personal factors—controlling only one factor will not be effective in decreasing MSDs. Based on understanding the interactions between biomechanical demand and psychosocial job factors, psychosocial job factors need to be included in all stages of MSD prevention programs, from assessment to management.