The Relationship Between BMI and Work-Related Musculoskeletal (MSK) Injury Rates is Modified by Job-Associated Level of MSK Injury Risk

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Objective: The aim of this study was to examine the relationship between body mass index (BMI) and occupational musculoskeletal (MSK) injury rates, and the statistical interaction between BMI and occupational exposure to MSK hazards (measured by level of MSK injury risk based on job category). **Methods:** Using 17 years of data from 38,214 university and health system employees, multivariate Poisson regression modeled the interaction between BMI and MSK injury risk on injury rates. **Results:** A significant interaction between BMI and MSK injury risk was observed. Although the effect of BMI was strongest for 'low' MSK injury risk occupations, absolute MSK injury rates for 'mid'/'high' MSK injury risk occupations remained larger. **Conclusions:** To address the occupational MSK injury burden, initiatives focused on optimal measures of workers' BMI are important but should not be prioritized over (or used in lieu of) interventions targeting job-specific MSK injury hazards.

Learning Objectives

- Discuss current understanding of the association between body mass index (BMI) and occupational health and safety, including the complex relationship between body mass and occupational exposures.
- Summarize the new findings on the association between BMI and occupational musculoskeletal (MSK) injury risk, and the interaction with exposure to job-related MSK hazards.
- Discuss the implications for targeting initiatives to address the burden of occupational MSK injuries.

BACKGROUND

Following a significant increase in the prevalence of obesity over the past several decades, approximately one in three adults in the United States is currently obese[1] [ie, body mass index (BMI) $\geq$30, where BMI = weight (in kilograms)/height (in meters^2)].[2] Obesity is associated with an increased risk of health conditions, including chronic diseases (eg, diabetes, hypertension, coronary artery disease), sleep apnea/disturbance, osteoarthritis, cancers, stroke, psychiatric disorders, musculoskeletal (MSK) disorders, and functional limitations related to posture, muscle strength, cardiorespiratory capacity, walking, motor tasks, fatigue, and disability.[3,4] In the workplace, obesity is associated with higher health and disability costs, increased absenteeism, reduced productivity, and higher rates of work-related injuries.[3–7]

Despite evidence of an association between BMI (and other body mass measures) and adverse occupational safety and health outcomes—even decades ago[8,9]—the mechanism of this relationship is deemed complex and remains unclear.[3–6,10] A biophysical framework suggests that obesity is associated with risk factors for unintentional injury such as comorbidities, psychotropic medication use, altered gait and balance, increased force in falls, reduced neural sensitivity, extremity friction, sleep apnea, and fatigue.[11] Further, the effect of obesity on unintentional injury may vary by injury type and mechanism. For example, although obese individuals may experience increased risk of and forces in a fall, their higher bone density and increased cushioning from fat could reduce their risk of fall-related fractures/dislocations.[6] In addition, physiological and biomechanical factors may influence injury risk through functional limitations,[3] and obese individuals may recover more slowly from an injury.[4]

Obese workers also face barriers within the work environment designed for normal-weight individuals.[3,6,12] For example, ergonomic designs implemented for normal-weight individuals may not meet the ergonomic needs of obese individuals, obesity may limit the availability or effectiveness of personal protective equipment (PPE), and obese individuals' thermal regulation may be compromised. There may be negative influences on work load for obese individuals as well, even within a given job title or occupational group. For example, an obese nurse may be asked to do more of the patient lifting and repositioning tasks than his/her normal-weight colleagues.[7] Finally, the relationship between obesity and occupational injury may be explained, in part, by differing propensities to formally report work-related injury events [eg, through the workers' compensation (WC) system].[7] These latter two patterns may reflect broader concerns of weight-based bias and disparities in the occupational setting.[3]

The concurrent consideration of body mass measures and occupational exposures in public health research is relatively new, yet important: these factors are interrelated, each may have an effect on adverse work-related outcomes, the workplace is a venue that may support effective interventions, and occupational safety and health as a discipline has interest in comprehensive worker health.[5] However, an understanding of the role of each factor has been hampered by the complex relationship between body mass and occupational exposures (eg, obesity can influence or be influenced by an occupational exposure, and it may act as a confounder or a modifier[5]), as well as practical limitations in research design and methods[13] and a lack of well-developed theoretical bases.[6] It has been suggested that future research on body mass and adverse occupational safety and health outcomes must acknowledge socio-demographic, clinical, and lifestyle characteristics that could

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confound the body mass and work-related injury association, such as age, sex, race/ethnicity, income, education, smoking status, physical activity, and health-related comorbidities.[4] In addition, there may be important interactive effects to consider,[4,5] particularly that between body mass and occupational exposures.

The purpose of this study was to build on prior research efforts[7] using data from a university and health system to more closely examine the relationship between BMI and work-related MSK injury rates, with a focus on the statistical interaction between BMI and a proxy for level of MSK injury risk based on job category. Given the potential for the BMI and work-related injury relationship to vary by type of injury, the focus was on work-related MSK injuries for which these workers are known to be at a high risk.[14,15] This study is part of a larger evaluation of the effect of an intervention to improve physical activity and healthy eating among workers in the university and health care system.[16,17]

METHODS

Data Source

Study data came from the Duke Health and Safety Surveillance System (DHSSS), a health-system specific initiative designed to provide comprehensive health information on employees of Duke University and Duke University Health System in North Carolina, USA.[18] Data for this research combined files within the DHSSS: Human Resources (HR), Health Risk Appraisal (HRA), WC, and employer-sponsored private health insurance medical and pharmacy claims. These data are de-identified, but each employee has a unique member number to allow data from these files to be linked at the individual level for analyses. A detailed description of how the DHSSS was constructed and its data sources,[18] as well as examples of its use in research,[7,15,19–21] have been published.

Population and Time at Risk

HR administrative data were used to identify demographic and work-related characteristics of the university and health system employees from January 1, 1997, through December 31, 2013: gender, race/ethnicity, age, occupational group, hours scheduled to work per week, and months of employment within the university and health system. Time at risk was measured as full-time equivalents (FTEs), where 1 FTE = 2000 hours worked per year per worker. FTEs were estimated for each worker by study year using the employees' usual work schedule of hours worked per week and duration of employment.

In these analyses, we defined the study cohort as any employee who 1) contributed work hours during the years 1997 through 2013, 2) completed at least one HRA during the years 1995 (when the HRA was first available) through 2013, and 3) belonged to an occupational group other than "missing," "unclassified," "student," "temporary services," and "long-term disability." At the university and health system, the HRA is available upon hiring and again annually to all employees eligible for health benefits, and participation is voluntary. HRA data were used to characterize employees' self-reported clinical and lifestyle factors, including BMI, physical activity level, smoking status, diabetes status, and amount of work and/or family stress. Two versions of the HRA were employed over this time period, one from 1995 through 2005 and one from 2006 through 2013; efforts were made to classify variables of interest in a parallel manner across the two versions.

In prior analyses with HRA data,[7] the first available HRA was used to define the start of study follow-up for an individual, with several key variables (ie, BMI and smoking status) treated as "fixed" for the remainder of the follow-up period. In this study, follow-up for an individual began the year in which the individual first contributed FTEs during the study period. Of the 38,214 employees in the study cohort, approximately 60% completed only one HRA during their time in the study cohort, and those data were applied to each year in which the employee was in the study cohort. Of employees who completed an HRA in more than one calendar year during their time in the study cohort (range 2 to 17), HRA variables were all treated as time-varying unless otherwise noted. In cases where employees did not complete an HRA in successive years, we applied the data from the most recent prior HRA to a given year without a completed HRA. If a prior completed HRA did not exist, we allowed data from the closest future HRA to be used. Among employees who completed more than one HRA in a calendar year, data from the most complete HRA (ie, least amount of missing data) were used. The average time between completion of an HRA and the calendar year of interest was 2.7 years (median 2, range 0 to 18).

Outcome

Work-Related MSK Injury

Using data from the WC claims database and similar to an approach used previously,[14] MSK injuries included events with a nature of injury code of pain/inflammation, sprain, strain, dislocation, twist, or carpal tunnel syndrome, and a cause code of fall/slip, exertion, lifting, push/pull, twisting, repetitive motion, or bodily reaction. The WC database also included information on the body part(s) affected. Multiple MSK injuries were allowed per individual over the study period. Each individual was considered to be at risk of MSK injury at any time they were contributing FTEs.

Exposure

Body Mass Index

BMI was categorized as less than 18.5 (underweight), 18.5 to 24.9 (recommended weight), 25 to 29.9 (overweight), 30 to 34.9 (obesity class I), 35 to 39.9 (obesity class II), or 40 or higher (obesity class III).[2]

Potential Effect Measure Modifier

Level of MSK Injury Risk Based on Job Category

Previously defined occupations in the HR data (Table 1) were grouped by level of MSK injury risk (high, mid, low) based on their crude rate of MSK injury during the study period. MSK injury risk levels comprised the following occupations: High (laundry, dietary service, nursing care assistant/patient transport, housekeeping, non-clinical technical/skilled craft), Mid (other service, physical/occupational therapy, nursing, other clinical, police/security, office support) and Low (pharmacy/dosimetry, administrative/managerial, information/research technology, faculty/research associate, physician/physician assistant). Occupation and level of MSK injury risk were treated as time-varying covariates.

Covariates

Diabetes

Study cohort members were classified as having diabetes in a given year if they met either or both of the following conditions: (1) self-reported diabetes in the HRA if the HRA was completed that year (ie, for analyses, HRA data for diabetes were not applied to prior or subsequent years) and (2) classification of diabetes in that year based on a modified version of National Committee for Quality Assurance, Healthcare Effectiveness Data and Information Set (HEDIS) criteria[22] applied to members' employer-sponsored private health insurance medical and pharmacy claims data. For the latter criterion, the HEDIS criteria of 12 months of insurance coverage and no more than 1-month gap in insurance coverage were relaxed to a criterion of having at least 1 month of employer-sponsored insurance coverage in the diagnosis year. Once classified as having diabetes in a given year, the study cohort member was classified as having diabetes in all subsequent years of observation.

TABLE 1. Stratified by Worker and Work-Related Characteristics, Frequency and Proportion of Full-Time Equivalents (FTEs) Contributed by the Study Cohort Compared With All University and Health System Employees, 1997–2013, With MSK Injury Frequencies, Rates, Rate Ratios, and 95% Confidence Intervals (CIs)

	All Employees* ($n = 112,519$)	Study Cohort*,† ($n = 38,214$)			
	FTE (%)	FTE (%)	MSK Injuries	Rate‡	Crude Rate Ratio (95% CI)
Sex					
Female	297,469 (63.1)	178,613 (69.8)	6,138	34.4	1.49 (1.39–1.61)
Male	174,155 (36.9)	77,172 (30.2)	1,775	23.0	1.00
Age, years					
<30	82,003 (17.4)	32,940 (12.9)	921	28.0	1.00
30 to <40	128,899 (27.3)	70,501 (27.6)	1,798	25.5	0.91 (0.82–1.02)
40 to <50	124,993 (26.5)	76,377 (29.9)	2,546	33.3	1.19 (1.08–1.32)
50 to <60	98,625 (20.9)	58,620 (22.9)	2,152	36.7	1.31 (1.18–1.46)
60+	37,104 (7.9)	17,347 (6.8)	496	28.6	1.02 (0.88–1.19)
Race					
White	319,764 (67.8)	161,804 (63.3)	3,873	23.9	1.00
Black or African-American	107,993 (22.9)	73,189 (28.6)	3,557	48.6	2.03 (1.91–2.16)
Other§	41,876 (8.9)	19,730 (7.7)	457	23.2	0.97 (0.85–1.10)
Missing	1,991 (0.4)	1,062 (0.4)	26	24.5	
Tenure, years					
<1	41,450 (8.8)	13,450 (5.3)	375	27.9	1.00
1 to <5	175,433 (37.2)	81,346 (31.8)	2,562	31.5	1.13 (0.97–1.31)
5 to <10	94,778 (20.1)	57,526 (22.5)	1,624	28.2	1.01 (0.87–1.18)
10+	159,963 (33.9)	103,464 (40.4)	3,352	32.4	1.16 (1.00–1.34)
Occupational group					
Administrative/Managerial	57,423 (12.2)	37,180 (14.5)	533	14.3	1.00
Dietary service	4,288 (0.9)	3,020 (1.2)	267	88.4	6.17 (5.21–7.30)
Faculty/Research associate	118,740 (25.2)	32,077 (12.5)	116	3.6	0.25 (0.20–0.32)
Housekeeping	12,683 (2.7)	8,608 (3.4)	720	83.6	5.83 (5.13–6.63)
Information/Research technology	50,144 (10.6)	32,002 (12.5)	395	12.3	0.86 (0.74–1.00)
Laundry	367 (0.1)	312 (0.1)	46	147.5	10.29 (7.29–14.5)
Nonclinical technical/Skilled craft	12,539 (2.7)	7,938 (3.1)	512	64.5	4.50 (3.92–5.17)
Nursing care assist./Patient transport	12,387 (2.6)	7,163 (2.8)	629	87.8	6.13 (5.37–6.99)
Nursing	59,899 (12.7)	34,252 (13.4)	1,759	51.4	4.00 (3.21–4.00)
Office support	70,669 (15.0)	49,732 (19.4)	1,340	26.9	1.88 (1.68–2.11)
Other clinical	38,578 (8.2)	24,696 (9.7)	1,086	44.0	3.07 (2.72–3.45)
Pharmacy/Dosimetry	5,497 (1.2)	3,352 (1.3)	56	16.7	1.17 (0.85–1.60)
Physical/Occupational therapy	3,081 (0.7)	1,714 (0.7)	89	51.9	3.62 (2.80–4.68)
Physician/Physician assistant	15,294 (3.2)	7,408 (2.9)	20	2.7	0.19 (0.11–0.31)
Police/Security	2,711 (0.6)	1,750 (0.7)	65	37.2	2.59 (1.93–3.48)
Other service	7,323 (1.6)	4,582 (1.8)	280	61.1	4.26 (3.61–5.03)
MSK injury risk group					
High‖	—	27,041 (10.6)	2,174	80.4	8.04 (7.48–8.64)
Mid¶	—	116,725 (45.6)	4,619	39.6	3.96 (3.71–4.22)
Low#	—	112,019 (43.8)	1,120	10.0	1.00

*Excludes occupational groups of missing, unclassified, students, temporary services, long-term disability.
†Employees who completed a Health Risk Appraisal at least one time between 1995 through 2013.
‡Injuries per 1,000 FTEs.
§Asian, Pacific Islander, American Indian, Alaskan Native, Hispanic, Indian, Native Hawaiian.
‖Laundry, dietary service, nursing care assistant/patient transport, housekeeping, nonclinical technical/skilled craft.
¶Other service, physical/occupational therapy, nursing, other clinical, police/security, office support.
#Pharmacy/dosimetry, administrative/managerial, information/research technology, faculty/research associate, physician/physician assistant.

Smoking

Smoking status was categorized by whether the participant self-identified as a ''current smoker'' (yes or no) in the HRA.

Physical Activity

Physical activity level was defined, again using data from the HRA, as the number of days per week in which the HRA participant engaged in 30 minutes or more of aerobic exercise: 0 days per week, 1 day per week, 2 or 3 days per week, 4 or 5 days per week, and 6 or 7 days per week. Categories were further combined for some analyses.

Work/Family Stress

HRA participants were asked about their levels/frequency of stress related to work and family (separately; first version of HRA) or life (second version of HRA), using a 5-point Likert scale. For those who responded ''none'' or ''little'' to both work and family stress (or ''seldom stressed'' or ''sometimes stressed'' in life), the study variable work/family stress was categorized as ''seldom/sometimes.'' For participants with at least, but not more than, ''some'' work or family stress (or ''often stressed'' in life), work/family stress was categorized as ''often.'' Finally, for participants with work or family stress categorized as ''a lot'' or ''overwhelming'' (or life stress as ''heavily stressed'' or

"excessively stressed"), work/family stress was categorized as "heavily/excessively."

Demographic and Work History Variables

HR administrative data were used to define demographic and work-related characteristics, including age, sex, race/ethnicity, and employment duration. Values of these variables were updated for each year of follow-up.

Analytical Approach

Descriptive analyses were conducted to characterize the frequency and proportion of the study cohort's time at risk and MSK injuries across demographic, work-related, clinical, and lifestyle factors. For demographic and work-related characteristics, the proportional distribution of the study cohort's time at risk was compared with that of the entire population at the university and health system during the study period. Differences in the proportional distribution of FTEs within categories of demographic, clinical, and lifestyle factors were assessed across BMI and occupation, as well as level of MSK injury risk.

Rates of MSK injury, overall and stratified across categories of interest, were expressed as the number of injuries per 1000 FTEs. Rate ratios (RRs) and 95% confidence intervals (95% CIs) were constructed assuming a Poisson distribution. In addition to examining rates of MSK injury across factors of interest, a multivariate Poisson model was constructed to model the statistical interaction between BMI and level of MSK injury risk on the basis of job category. An initial, hierarchically sound full model contained all variables of interest: BMI category, occupational group, BMI category x occupational group, sex, age, race, institutional tenure, calendar year, exercise frequency, stress level, diabetes, and smoking status. A backward elimination strategy was employed in which insignificant variables (based on Type III likelihood ratio $P > 0.10$) were removed, given their removal did not lead to a more than 10% change in other estimates. Through this process, diabetes was removed from the model. In addition, consideration was paid to the potential for collinearity among age, tenure, and calendar year; diagnostic evaluation did not suggest concern for their simultaneous inclusion in the model.

Study procedures were approved by the Duke University Health System Institutional Review Board.

RESULTS

Description of the Study Cohort

The study cohort comprised 38,214 employees who provided HRA data and contributed 255,785 FTEs between 1997 and 2013 (Table 1). The average follow-up time was 7.7 years (compared with 5.5 for the university and health system). Most were female (70%), and the more common racial groups were White (63%) and Black/African American (29%). More common occupational groups included office support (19%), administrative/managerial (14%), nursing (13%), faculty (13%), and information/research technology (13%). Forty percent of the follow-up time was contributed by those with 10 or more years of institutional tenure. Compared with the population of all employees at the university and health system, the study cohort had a higher proportion of time at risk contributed by workers who were female, Black/African American, older, and with a greater number of years of institutional tenure. The study cohort also had a higher proportion of FTEs among employees in office support, information/research technology, administrative/managerial, and nursing occupations, and a lower than expected proportion among faculty/research associates.

Demographic, Occupational, Clinical, and Lifestyle Characteristics by BMI, Occupation, and Level of MSK Injury Risk Based on Job Category

The distribution of FTEs within some demographic, work-related, clinical, and lifestyle factors varied by BMI (Table 2). The proportion of FTEs categorized as female gender increased with increasing BMI for those who were overweight/obese, and the proportion categorized as nonwhite increased with increasing BMI (excluding the underweight category). There was not a monotonic pattern in median age by BMI, although it was lowest among those categorized as underweight (35 years) and increased to 45 years for those in obese class I. By institutional tenure, years of service increased, though not monotonically, with increasing BMI. The proportion of FTEs categorized as physically less active (exercise frequency of <2 days/week), having diabetes, and experiencing heavy/excessive stress generally increased with increasing BMI. Finally, smoking was more prevalent among underweight and overweight/obese FTEs than those of recommended weight.

Variation was also observed in several demographic, work-related, clinical, and lifestyle factors across occupation and level of MSK injury risk. There was not a monotonic pattern in gender distribution by level of MSK injury risk. However, occupations with a relatively high proportion of males included nonclinical technical/skilled craft (86.2%), police/security (77.3%), faculty/research associate (59.6%), and physician/physician assistant (55.2%). Those with a relatively high proportion of females included nursing (91.3%), office support (88.9%), and nursing care assistant/patient transport (78.0%). The proportion of FTEs categorized as nonwhite increased with an increasing level of MSK injury risk. Compared with the study cohort, several occupations (all with a high level of MSK injury risk) comprised a large proportion of nonwhite workers: laundry (99.0%), dietary service (95.8%), housekeeping (96.7%), and nursing care assistant/patient transport (74.1%). Other occupational groups included a relatively high proportion of white workers: physical/occupational therapy (89.6%), administrative/managerial (77.5%), physician/physician assistant (74.0%), and faculty/research associate (73.7%).

Median age decreased slightly with decreasing level of MSK injury risk, with relatively high median age values among laundry (47 years) and other service (47 years) and relatively low median age values among physician/physician assistant (31 years) and physical/occupational therapy (36 years), compared with the cohort median age of 42 years. By institutional tenure, there was decreasing MSK injury risk with decreasing years of service. Median years of institutional tenure was higher for laundry (13.1 years) and dietary service (11.8 years) and lower for physician/physician assistant (2.5 years) and nursing care assistant/patient transport (3.3 years).

Nearly one-third of the FTEs (30%) was categorized as obese (ie, BMI $\geq$30). Workers in occupations categorized as having a high level of MSK injury risk exhibited a greater proportion of FTEs categorized as obese, with particularly high proportions among laundry (54.4%), dietary service (54.1%), and housekeeping (51.4%). Lower proportions of FTEs categorized as obese were observed among workers in occupational groups with mid and low levels of MSK injury risk, with notably low proportions among physical/occupational therapy (9.9%), faculty/research associates (9.5%), and physician/physician assistant (7.5%).

When examining the proportion of FTEs characterized as having diabetes (6.8% overall) or being a current smoker (11.1% overall), similar patterns were observed as those for obesity: diabetes (high MSK injury risk: 12.3%, mid: 8.1%, low: 4.4%) and for current smoking (high: 25.8%, mid: 12.6%, low: 6.0%). Regarding physical activity level, one-fifth of the study cohort

TABLE 2. Proportional Distribution of FTEs* Across Gender, Race, Clinical Characteristics, and Lifestyle Factors, as well as Median Years of Age and Institutional Tenure, With Stratification by MSK Injury Risk Group, Occupational Group, and Body Mass Index (BMI)

MSK Injury Risk Group	% Female Gender	% Nonwhite Race†	Median Years of Age	Median Years of Tenure	% Obese (BMI ≥30)	% Diabetic‡	% Current Smoker§	% Exercise <2 days/ week‖	% Excessively Stressed‖
High	**54.6**	**72.5**	**43**	**7.1**	**45.9**	**12.3**	**25.8**	**21.0**	**11.2**
Laundry	65.8	99.0	47	13.1	54.4	34.4	48.9	25.7	25.8
Dietary service	68.9	95.8	43	11.8	54.1	14.3	31.8	28.1	16.3
Nursing care assist./Patient transport	78.0	74.1	39	3.3	47.7	9.5	17.6	23.1	9.5
Housekeeping	67.4	96.7	45	8.5	51.4	16.1	31.0	22.0	12.3
Nonclinical technical/Skilled craft	13.8	36.7	45	10.1	34.8	9.9	24.5	15.2	9.3
Mid	**84.1**	**38.1**	**42**	**6.9**	**36.6**	**8.1**	**12.6**	**21.9**	**13.2**
Other service	52.5	64.0	47	9.0	43.8	11.5	22.1	22.5	12.3
Physical/Occup. Therapy	76.8	10.4	36	3.9	9.9	0.6	1.8	5.0	10.8
Nursing	91.3	23.5	41	5.7	28.9	5.5	7.6	18.8	13.8
Other clinical	75.3	34.8	41	7.0	31.6	7.2	10.9	20.4	12.8
Police/Security	22.7	43.4	42	5.5	39.3	8.3	14.7	13.4	11.1
Office support	88.9	48.4	43	7.7	44.6	10.3	16.3	25.9	13.2
Low	**58.6**	**26.2**	**41**	**6.3**	**20.3**	**4.4**	**6.0**	**19.2**	**12.5**
Pharmacy/ Dosimetry	71.8	37.2	38	5.7	30.9	3.4	6.8	18.6	13.6
Administrative/ Managerial	73.6	22.5	45	8.2	26.9	5.3	7.9	20.7	13.8
Information/ Research technology	61.2	29.5	41	6.6	25.2	5.4	8.8	20.5	11.2
Faculty/Research associate	40.4	26.3	41	6.0	9.5	3.4	2.8	16.8	12.3
Physician/ Physician assistant	44.8	26.0	31	2.5	7.5	1.0	2.1	17.2	12.8
Body mass index‖									
<18.5 (Underweight)	84.1	34.4	35	4.9	—	5.0	13.3	18.1	15.8
18.5–24.9 (Recommended)	72.2	26.7	39	5.3	—	4.1	8.8	14.9	11.4
25.0–29.9 (Overweight)	59.4	35.7	44	7.2	—	9.9	12.7	18.6	12.9
30.0–34.9 (Obese, class I)	70.1	46.0	45	8.2	—	19.9	12.4	25.5	13.0
35.0–39.9 (Obese, class II)	80.6	52.6	44	8.1	—	28.0	13.7	32.1	15.5
≥40.0 (Obese, class III)	86.3	55.9	43	8.9	—	35.6	10.1	38.8	13.5

*Proportion values are based on nonmissing data.
†Black/African-American, Asian, Pacific Islander, American Indian, Alaskan Native, Hispanic, Indian, Native Hawaiian.
‡Based on diabetes as self-reported in the HRA or captured using modified HEDIS criteria applied to employer-sponsored private health insurance claims data.
§Based on smoking status as reported in HRA.
‖Based on most recent HRA data, regardless of whether HRA completed in a calendar year in which data were applied.

engaged in exercise less than 2 days/week. This proportion varied little across MSK injury risk levels. However, it was somewhat higher among dietary service (28.1%), office support (25.9%), and laundry (25.7%). Levels of physical activity were particularly high for physical/occupational therapy, with 67.1% of FTEs with an exercise frequency of at least 4 days/week. Finally, although the proportion of FTEs categorized as heavily/excessively stressed was lowest for those with a high level of MSK injury risk (11.2%), a notably high proportion was observed among laundry (25.8%) and dietary service (16.3%).

Work-related MSK Injuries

One-quarter (26.8%; $n = 7913$) of the WC injury claims reported and accepted for this cohort were for MSK injuries. These events more commonly affected the back (31.7%; 2512), lower extremities (18.3%; 1451), and shoulder/neck (11.4%; $n = 904$). The overall rate of MSK injury was 30.9 events per 1000 FTE. Although the pattern was not monotonic, MSK injury rates declined during the period of observation, from 37.0 events per 1000 FTE in 1997 to 21.7 events per 1000 FTE in 2013. By demographic

TABLE 3. Frequency and Proportion of FTEs, and Frequency, Rate, Rate Ratios, and 95% Confidence Intervals (CIs) of MSK Injuries by Lifestyle and Clinical Characteristics

	FTE (%)	MSK Injuries	Rate*	Crude Rate Ratio (95% CI)
Body mass index				
<18.5 (Underweight)	4,753 (1.9)	91	19.1	0.92 (0.73–1.17)
18.5–24.9 (Recommended)	95,097 (37.3)	1,969	20.7	1.00
25.0–29.9 (Overweight)	77,383 (30.4)	2,269	29.3	1.42 (1.33–1.51)
30.0–34.9 (Obese, class I)	41,117 (16.1)	1,718	41.8	2.02 (1.88–2.17)
35.0–39.9 (Obese, class II)	19,390 (7.6)	979	50.5	2.44 (2.24–2.65)
≥40.0 (Obese, class III)	16,966 (6.7)	837	49.3	2.38 (2.18–2.60)
Missing	1,078	50		
Diabetes				
Yes	13,535 (6.8)	602	44.5	1.53 (1.40–1.68)
No	184,546 (93.2)	5,356	29.0	1.00
Missing	57,704	1,955		
Exercise frequency				
0 days/week	15,654 (8.4)	593	37.9	1.30 (1.16–1.46)
1 day/week	22,495 (12.1)	711	31.6	1.09 (0.98–1.21)
2–3 days/week	65,461 (35.3)	1,922	29.4	1.01 (0.93–1.10)
4–5 days/week	49,303 (26.6)	1,286	26.1	0.90 (0.82–0.98)
6–7 days/week	32,574 (17.6)	947	29.1	1.00
Missing	70,298	2,454		
Current smoker				
Yes	27,876 (11.1)	1,427	51.2	1.80 (1.69–1.91)
No	222,786 (88.9)	6,348	28.5	1.00
Missing	5,123	138		
Stress				
Seldom/Sometimes	133,278 (59.9)	3,697	27.7	1.00
Often	60,813 (27.3)	1,748	28.7	1.04 (0.97–1.10)
Heavily/Excessively	28,287 (12.7)	1,163	41.1	1.48 (1.38–1.59)
Missing	33,408	1,305		

*Injuries per 1,000 FTEs.

characteristics, rates were higher among females, workers age 40 to less than 60 years compared with younger and older counterparts, Black/African American workers compared with whites and other races, and workers with 10+ years of institutional tenure compared with those with less than 10 years (Table 1).

MSK injury rates increased with increasing BMI, and they were over two times higher among obese individuals than those with a recommended BMI (Table 3). Rates were higher for workers with diabetes, smokers, and those with a heavy/excessive level of perceived work/life stress. Rates of MSK injury decreased with increasing days per week of exercise, with the exception of 6 to 7 days per week in which rates began to increase again. Finally, rates varied significantly by occupation; by level of job-associated MSK injury risk, the high risk group had an overall rate of MSK injury eight times that of the low risk group (Table 1).

A significant statistical interaction between BMI and occupational exposure to MSK hazards, as measured by level of MSK injury risk based on job category, was observed in multivariate analyses (Type III $P < 0.0001$; Table 4). The strongest effect of BMI on MSK injury rates was observed among workers in occupations with a low level of MSK injury risk. The positive association between BMI and MSK injury rates was significant, but of lower magnitude, among workers with mid and high levels of MSK injury risk. However, rates of MSK injuries among workers of any BMI category in mid and high MSK injury risk occupations still exceeded that of obese workers in low MSK injury risk occupations (Fig. 1).

DISCUSSION

Few prior studies have examined the statistical interaction between BMI and occupational hazards on work-related injury, and although results on its significance have been mixed,[6,7,9] its consideration is recommended.[4] Two related models have been defined to address the potential interactive effect of BMI and occupational exposure on adverse work-related outcomes: 1) BMI modifies the relationship between occupational exposure and outcome and 2) occupational exposure modifies the relationship between BMI and occupational outcome.[5] Prior longitudinal analyses of data from university and health system workers examined the effect of BMI on the rate of work-related injury overall and related outcomes (ie, days lost, costs).[7,23] Similar to this study, a positive linear association between BMI and work-related injury rates was found.[7]

Compared with workers with a recommended BMI, workers who were overweight or obese had elevated MSK injury rates. The magnitude of this effect varied by level of MSK injury risk (based on job category) and was greatest for occupational groups with low MSK injury risk. These findings are in line with a prior study of the Canadian workforce using data from the National Population Health Survey, which suggests that the magnitude of the relative difference in injury rates between obese and normal weight individuals is greater in workers in more sedentary occupations.[6] This pattern is noteworthy, but the mechanisms behind it are unknown. It should not be implied that injury prevention should be narrowly focused on occupations with low MSK injury risk/sedentary occupations. In fact, absolute rates of MSK injuries among workers in occupations with mid and high MSK injury risk levels across all BMI categories still exceeded rates of MSK injury among all—including obese—workers in low MSK injury risk occupations, even when controlling for differences in several demographic, clinical, and lifestyle characteristics. It should not be overlooked that many of the occupational groups in the high MSK injury risk group also exhibit poorer general health indicators (ie, exercise frequency, smoking status, diabetes, BMI, and work/family stress).

TABLE 4. Stratified by Musculoskeletal (MSK) Injury Risk Group, Unadjusted and Adjusted Rates, Relative Differences in Rates, and 95% Confidence Intervals (CIs) of MSK injury by Body Mass Index (BMI) Category

MSK Injury Risk	FTE	MSK Injuries	Unadjusted Rate* ± SD	Crude Rate Ratio (95% CI)	Adjusted Rate† ± SE	Adjusted Rate Ratio (95% CI) †
High‡						
<18.5 (Underweight)	355	20	56.4 ± 8.4	0.84 (0.54–1.32)	84.0 ± 21.8	1.16 (0.69–1.97)
18.5–24.9 (Recommended)	5,192	347	66.8 ± 8.4	1.00	72.2 ± 5.7	1.00
25.0–29.9 (Overweight)	9,041	666	73.7 ± 9.1	1.10 (0.97–1.25)	94.6 ± 5.5	1.31 (1.10–1.56)
30.0–34.9 (Obese, class I)	6,233	551	88.4 ± 9.6	1.32 (1.16–1.52)	113.5 ± 7.2	1.57 (1.31–1.89)
35.0–39.9 (Obese, class II)	3,419	329	96.2 ± 10.3	1.44 (1.24–1.67)	120.1 ± 9.5	1.66 (1.36–2.04)
≥40.0 (Obese, class III)	2,712	252	92.9 ± 9.9	1.39 (1.18–1.64)	97.1 ± 9.1	1.34 (1.07–1.69)
Missing	88	9				
Mid§						
<18.5 (Underweight)	1,912	54	28.2 ± 5.8	0.82 (0.62–1.07)	34.1 ± 5.5	0.82 (0.60–1.13)
18.5–24.9 (Recommended)	37,921	1,310	34.5 ± 6.2	1.00	41.6 ± 2.0	1.00
25.0–29.9 (Overweight)	33,726	1,245	36.9 ± 6.4	1.07 (0.99–1.15)	43.5 ± 2.0	1.05 (0.95–1.15)
30.0–34.9 (Obese, class I)	21,327	941	44.1 ± 6.9	1.28 (1.17–1.39)	49.0 ± 2.6	1.18 (1.06–1.33)
35.0–39.9 (Obese, class II)	10,844	544	50.2 ± 7.7	1.45 (1.31–1.60)	49.7 ± 3.2	1.19 (1.05–1.36)
≥40.0 (Obese, class III)	10,311	491	47.6 ± 7.7	1.38 (1.24–1.53)	54.0 ± 3.5	1.30 (1.14–1.48)
Missing	684	34				
Low‖						
<18.5 (Underweight)	2,486	17	6.8 ± 2.6	1.14 (0.70–1.86)	8.8 ± 2.5	1.15 (0.66–2.00)
18.5–24.9 (Recommended)	51,984	312	6.0 ± 2.4	1.00	7.7 ± 0.6	1.00
25.0–29.9 (Overweight)	34,615	358	10.3 ± 3.3	1.72 (1.48–2.01)	13.0 ± 0.9	1.70 (1.42–2.04)
30.0–34.9 (Obese, class I)	13,558	226	16.7 ± 4.1	2.78 (2.34–3.30)	21.3 ± 1.8	2.78 (2.26–3.40)
35.0–39.9 (Obese, class II)	5,127	106	20.7 ± 4.6	3.44 (2.76–4.29)	21.1 ± 2.7	2.74 (2.07–3.63)
≥40.0 (Obese, class III)	3,944	94	23.8 ± 5.3	3.97 (3.15–5.00)	29.5 ± 3.7	3.85 (2.92–5.06)
Missing	306	7				

SD, standard deviation; SE, standard error.
*Injuries per 1,000 FTEs.
†Multivariate model is hierarchically sound and includes the interaction between BMI category and occupational group, adjusted for sex, age, race, institutional tenure, calendar year, exercise frequency, stress level, and current smoking status.
‡Laundry, dietary service, nursing care assistant/patient transport, housekeeping, non-clinical technical/skilled craft.
§Other service, physical/occupational therapy, nursing, other clinical, police/security, office support.
‖Pharmacy/dosimetry, administrative/managerial, information/research technology, faculty/research associate, physician/physician assistant.

The importance of concurrent consideration of body mass and occupational hazards in understanding work-related injury has been justified, in part, through recognition of the importance of comprehensive worker health (eg, NIOSH's Total Worker Health initiative: https://www.cdc.gov/niosh/twh/) and of the workplace as a setting that may support effective interventions.[5] However, many studies focused on the relationship between BMI and work-related injury call for employer-initiated interventions focused on employee health promotion and wellness through weight reduction, lifestyle changes, etc.—with an emphasis on outcome metrics such as employee productivity and cost savings from an employer's perspective. Indeed, such a health promotion component is important—and called for by NIOSH's Total Worker Health initiative—but as a standalone intervention, it cannot be expected to prevent work-related injuries to a meaningful degree; lifestyle interventions should be delivered in parallel with injury prevention components that address safety hazards associated with work tasks themselves.[4] Further, an unjustified narrow (or prioritized) consideration of body mass as a predictor of work-related injury may inhibit the development and implementation of more effective injury prevention approaches, as well as promulgate unintended harm to workers through ethical, legal, and social mechanisms (eg, ''anti-fat bias'' and stigmatization, hiring/termination practices, risk assessment, investment in PPE and intervention development rather than hazard elimination, and injury reporting/claims acceptance).[5,24]

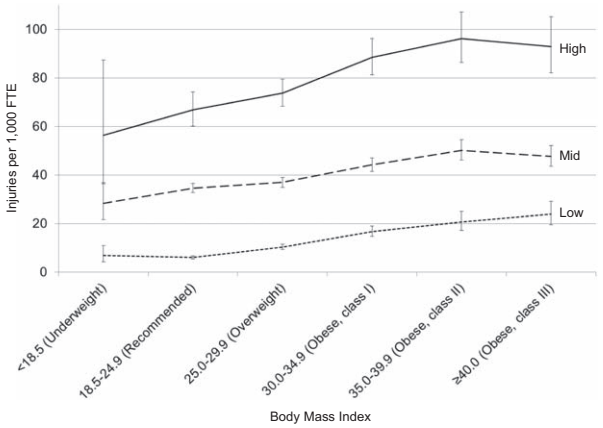

FIGURE 1. Crude MSK injury rates with 95% confidence intervals by body mass index category, stratified by job associated level of MSK injury risk (ie, High, Mid, Low).

Limitations and Strengths

Several limitations of this study are inherent in the DHSSS data themselves. Information on BMI, lifestyle factors, and most clinical factors was only available for workers who completed an HRA, and such data were not always complete. We do not expect there to be systematic differences between those who participated in the HRA and those who did not.[7] However, there may be variation in whether employees completed an HRA on a regular basis (allowing for inclusion of more up-to-date values of time-varying variables) and whether questions were interpreted as intended (n.b., the HRA

was provided in English only). Self-reported data may be subject to recall bias or misclassification. For example, the tendency to under-report weight, particularly among overweight and obese individuals,[25] would have led to an underestimate in the magnitude of BMI effects within each MSK injury risk group. Although data were robust for the analyses performed, we lacked statistical power to make meaningful comparisons in the relationship between BMI and work-related injury across unique, more specific, occupational groups. Finally, we lacked information on some factors relevant to the primary research question being asked. Data were not available on several potential confounders of the relationship examined: shift work, socioeconomic status, educational background, family living arrangements/marital status, and actual work exposures. However, we note that the relationships examined are complex; it is plausible that some variables are on the same causal pathway, and their concurrent inclusion in multivariate models would lead to over-adjustment. In addition, occupation-specific data on exposure to sedentary behavior or physical activity, the inclusion of which has been recommended,[4] were not available.

Regarding data related to work-related injuries, only outcomes that were reported and accepted through the WC system were captured. The under-capturing of work-related injuries through the WC system, particularly those of a MSK nature, has been well-described.[26–30] These data do not allow us to address this concern, or that of whether reporting of (and acceptance of) WC claims, for injuries in general or specific to initial or recurrent MSK injuries, varies by BMI level.

Despite these limitations, this study builds on prior literature, and many of its strengths are also inherent properties of the data sources—both individually and in their linkage. The large, well-defined cohort with individual-level data on demographic, work-related, clinical, and lifestyle characteristics, coupled with information on time at risk, afforded a longitudinal appraisal of MSK injury rates over a 17-year period. Data were robust enough to examine patterns in characteristics of interest across meaningful occupational groupings and control for the potential confounding effects of these characteristics in examining the interactive effect of interest, that is, effect measure modification of BMI on work-related MSK injury rates by job-associated level of MSK injury risk. In addition, consideration of the outcome of work-related MSK injury rates, rather than work-related injury rates overall, was also an important feature in line with literature-based recommendations.[6] Finally, the university and health system is the second largest private employer in North Carolina,[31] and results are broadly generalizable to a range of occupational groups common to university and health system settings and adult worker demographic, clinical, and lifestyle characteristics.

CONCLUSIONS

This study demonstrates the feasibility of using multi-source longitudinal surveillance data to explore rates of MSK injury events and provide a robust appraisal of workers' safety, health, and well-being. Recognizing limitations inherent in the use of WC claims data alone to define outcomes of interest, future research incorporating other sources of MSK injury data, such as workers' private health insurance claims, may provide a more comprehensive understanding of workers' safety and health.

Compared with workers with normal BMI, workers who were overweight or obese had elevated MSK injury rates. In line with prior research, findings from this study suggest that BMI and occupation are both strong predictors of MSK injury, and that the relationship between BMI and work-related injury varies across occupations, with a greater magnitude of the effect of BMI observed in occupations characterized by lower general MSK injury risk. Examination of the relationship between BMI and work-related MSK injury, and evaluation of interventions designed to address the effects of BMI, should consider the potential modifying effect of occupational group, as well as differences in demographic, work-related, clinical, and lifestyle characteristics by occupational group that may confound the relationships of interest. Although the effect was attenuated for occupational groups with mid and high risk of MSK injury, concerns surround these groups with respect to workers' exercise frequency, smoking status, diabetes, BMI, and work/family stress, as well as broader social and cultural measures. Further, in occupational groups known to have relatively high levels of MSK injury risk, rates of MSK injuries among workers—regardless of BMI—still exceeded the high rates of MSK injury among obese workers in occupations with low levels of MSK injury risk. Thus, although workplace policies and programs focused on reaching optimal measures of workers' health such as body mass are important, they should not be prioritized over or used in lieu of interventions targeting occupational MSK injury hazards when working to address the burden of MSK injuries.

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