Efficacy of the Revised NIOSH Lifting Equation to Predict Risk of Low Back Pain Due to Manual Lifting

Expanded Cross-Sectional Analysis

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Objective: To evaluate whether the Revised NIOSH Lifting Equation (RNLE) is a valid tool for assessing risk of low back pain (LBP) due to manual lifting by using combined data from two cross-sectional studies of 1-year prevalence. **Methods:** Results from a symptom and occupational history questionnaire and RNLE analysis for 677 subjects employed in 125 manual lifting jobs at nine industrial sites were combined from two studies. **Results:** The odds of LBP increased as the lifting index (LI) increased from 1.0 to 3.0. A statistically significant odds ratio (OR) was found for both the $1 < LI \leq 2$ ($OR = 1.81$) and the $2 < LI \leq 3$ categories ($OR = 2.26$). For jobs with an LI value greater than 3.0, however, the OR remained nonsignificant. The $2 < LI \leq 3$ group remained statistically significant after adjusting for age, gender, body mass index, and psychosocial factors. **Conclusions:** It is clear that as the LI increases, the risk of LBP increases. Longitudinal studies are needed.

There is significant interest in identifying hazardous lifting tasks because low back pain (LBP) continues to affect a large percentage of workers. In 2008, almost 40% of the 1,078,140 injury and illness cases reported to the US Bureau of Labor Statistics were due to sprains and strains.[1] Overexertion was the reported cause in 45% of those cases and the back was the most frequently affected body part (40% of the cases).[1] The median number of days away from work for a case involving overexertion in lifting was 10 days.[1] It has been estimated that as many as 30% of the American workforce regularly perform potentially hazardous material handling as a part of their job.[2] The economic costs due to LBP are staggering.[3] In 1998, total health care expenditures incurred by individuals with LBP in the United States reached \$90.7 billion.[4] Results from a large sample of US households revealed that LBP accounted for about one quarter of the workers' compensation claims in the United States.[5] Recent data showed that workplace overexertion injuries (predominantly caused by lifting, pushing, pulling, and manual materials handling) accounted for about 24% of the total workers' compensation costs, which were estimated about \$12.7 billion in 2009.[6] Many back disorders have been linked to specific high-risk occupational lifting activities that cause excessive biomechanical and physiological loading on the workers, as well as psychosocial factors.[5,7–10]

In response to this enormous problem, the National Institute for Occupational Safety and Health (NIOSH) developed a practical analysis tool for evaluating the physical demands of two-handed manual lifting tasks.[11,12] The analysis tool consists of two equations, the recommended weight limit (RWL) and lifting index (LI), for evaluating a specified manual lifting task. The RWL is computed from a simple mathematical equation requiring measurement and input of characteristics that describe the task, such as the geometry of the hand location, frequency of lifting, work duration, and type of hand coupling required for the task. The LI provides an estimate of the relative physical demand for the task and is defined as the ratio of the actual weight of the load lifted divided by the RWL for the job (ie, LI = Load/RWL). A description of the criteria and rationale used to develop the RWL and LI was published by Waters et al, in 1993.[11] Researchers have shown that individuals can be reliably trained to obtain the data for the RWL and LI equations for use in field studies.[13] The purpose of this article is to provide additional epidemiologic data to evaluate the relationship between the LI and the prevalence and severity of lifting-related LBP.

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METHODS

Study Description

In a previous article, we presented findings from a cross-sectional study of manual-lifting exposures and LBP that examined the efficacy of the NIOSH lifting equation (NLE) to predict risk of LBP, but the sample size was small.[14] This article expands on that study and presents similar findings as previously published but combines the original data with additional subjects and jobs to increase the sample size. The study methods and procedures for obtaining the new data were nearly identical to those used in the previous study.[14]

In brief, the main elements of the study included the following:

1. Selection of manual lifting jobs (exposed) at five additional plants.
2. Selection of control or nonlifting jobs (unexposed) at selected plants.
3. Measurement of data needed to calculate the RWL and LI for each of the selected jobs.
4. Completion of a self-administered questionnaire by workers in each of the exposed and unexposed jobs.

Selection of Study Sites and Jobs

Five additional industrial facilities with a wide range of manual lifting jobs volunteered to participate in this study. Lifting jobs were selected for inclusion in the study on the basis of observations of representative workers and through discussions with plant personnel. The NIOSH investigators were blinded to whether workers reported LBP or other injury rates for all jobs but were not blinded with regard to whether the workers were in an exposed or control job. The inclusion and exclusion criteria used for selecting jobs in the exposed or lifting group were the following:

1. Jobs in which manual lifting is performed as a regular daily task activity, with at least 25 lifts per day.
2. Jobs with no major changes in content, pace, and work practices for the last 2 years.
3. Jobs with little or no unpredictable variations in task characteristics.
4. Jobs that complied with the application criteria of the RWL.[12] That is, none involved one-handed lifting, seated lifting, lifting in a restricted work space, or handling unstable objects, and none required significant amounts of nonlifting physical demands, such

as pushing, pulling, or carrying. Some of the selected jobs did, however, involve shifts lasting up to 12 hours.

5. Jobs that do not involve exposure to significant whole body vibration (eg, driving a truck more than 4 hours per day).

In addition to the original 50 lifting jobs previously analyzed and reported by Waters et al,[14] data from 75 additional lifting jobs were added in this study. The original 50 jobs included manual lifting of various parts for assembly of diesel engines at an engine manufacturing plant, fiberglass insulation products at a manufacturing plant, and stacks of papers and books at a printing office. Of the 75 new jobs added in this study, 17 were located at an automotive metal casting foundry, where workers performed various tasks that involved lifting sand castings of different sizes and weights from various positions. The lifting tasks typically required workers to repetitively lift sand castings weighing between 7 and 26 lb from manufacturing machines onto conveyor belts or racks, or from conveyors or racks into metal casting molds. Another 12 jobs were located at a paper-printing plant, where workers performed common lifting tasks requiring lifting of stacks of papers into printing machines or unloading printed materials from printing machines. The bundles typically weighed between 10 and 43 lb. Another two jobs were located at an egg-processing plant, where large quantities of eggs were fed into a machine for processing into powder and liquid forms, and powdered egg product was boxed and stacked for shipment. The manual handling jobs at the egg-processing plant typically involved lifting flats of eggs weighing between 8 and 16 lb and lifting boxes weighing approximately 50 lb. Another five jobs were located at a woven textile fabric manufacturing plant, where synthetic fiber material was made, processed into final sheets of finished material, and packaged on rolls for shipment. The weights handled varied between 26 lb and 94 lb. Finally, another 39 lifting jobs were added from an appliance manufacturing plant, where workers manufactured, painted, and assembled dryers. Lifting jobs included lifting parts from the manufacturing lines onto racks or overhead conveyors, lifting parts from one overhead conveyor to another overhead conveyor during the painting process, or lifting parts out of racks or bins for component or unit assembly. The weights of items lifted at the appliance manufacturing plant ranged between 7 and 22 lb.

As in the previous study, (1) workers with less than 12 months on the job were not included in the analysis, (2) workers included in the unexposed group were typically employed in office-related jobs that did not require lifting, and (3) workers in the unexposed group were excluded from the study if they reported heavy pushing or pulling more than 10 times per day, lifting 25 lb or more 10 times per day or more, or lifting 50 lb even once per day. Thus, the exposed population was defined as those who perform the selected manual-lifting jobs and the unexposed population is defined as a group of workers with no significant exposure at the time of the study to either lifting or other work-related risk factors for LBP, except prolonged sitting. Workers performing jobs in the unexposed group, however, could have been exposed to lifting on previous jobs. Each worker employed in the selected exposed and unexposed jobs was asked to complete a self-administered symptom and occupational history questionnaire. Participation was voluntary and there was no penalty for not completing the questionnaire.

DATA COLLECTED

Data were collected by individuals trained to make the measurements in a standardized manner. It has been shown that reliable measurements are obtained if standardized measurement methods are used.[13] Workers were observed and interviewed to identify individual tasks within the job and to document the task times and workstation layout. The following data were collected for each selected job to calculate the RWL and LI: weight of the object lifted, duration the task was performed during the day in hours, frequency of the lift in lifts per minute, vertical and horizontal distances at the origin and destination of the lift, coupling rating, angle of asymmetry at the origin, and destination of the lift in degrees. A sample of workers doing each of the exposed jobs were observed and analyzed during a 2- to 4-day period. Although multiple measurements were made for each job, there were insufficient data to evaluate interrater or task factor variability in this phase of the study. A minimum of three sets of repeated measurements were made for each of the exposed jobs at various times during the workday throughout the observation period. The number of workers observed and the frequency of measurements varied between jobs, depending upon the potential for variability in task factors within and between workers doing the same job.

Some lifting jobs required multiple lifting activities, each with a unique set of task characteristics. The NLE allows for the computation of a composite lifting index (CLI), such that the combined effects of all the tasks are considered. The CLI takes into account not only the LI for the single most stressful task but also includes the incremental increase in the LI as each subsequent task is added to the job.[12]

Calculation of RWL and LI

To reduce measurement bias in the calculations, averages were taken across all samples for all measurements to compute the LI and CLI values for each job. It was not possible to do the analysis with job as a cluster instead of just averaging individuals within one type of job because data were not collected for every worker in every job. Confounders were not averaged per job but were included for each participant. For jobs with variability in one or more factors due to the design of the job, such as when the vertical height or horizontal distance at the origin or destination varied from lift to lift, both a minimum, and maximum LI, and CLI value was computed for a worst case and best case assessment. Only the worst case values were used for risk modeling in the analysis. We adopted this approach for three reasons: (1) there is no procedure available for computing the LI for jobs with extreme variability; (2) we did not collect sufficient data regarding the distribution of the variability, making it impractical to determine an LI value on the basis of mean lifting characteristics; and (3) our approach would result in an overestimate of the risk rather than an underestimate, thereby biasing our results toward the null. In a few cases, there were significant differences between data samples (ie, when the differences in measurements would result in more than a 5% to 10% difference in the LI or CLI value). In these cases, a certified professional ergonomist reviewed the videotape of the job, simulated the lifting task, and made a judgment about what the appropriate measurements should be for the computations.

Horizontal Distance Adjustments

The measured horizontal distance (H) exceeded the 25-in maximum limit set by NIOSH for a fraction of the jobs. For purposes of this study, H was set equal to 25 in for jobs in which the measured H exceeded 25 in for two reasons. First, when the horizontal multiplier is set to 0, the LI approaches infinity, and the LI cannot be used to distinguish between jobs. Second, in nearly all cases where H exceeded 25 in, the worker leaned over and centered their weight over one foot, as opposed to centering their weight over the midpoint between their ankles. When this happened, the maximum horizontal distance from the L5/S1 joint translated to a point approximately over the weight bearing foot, and the horizontal moment was maintained at about 25 in. We recognize that not allowing H to exceed 25 in could result in an underestimate of risk, and that setting H equal to 25 in, when it may be less because the worker leans on one foot, could result in an overestimate of risk.

Job Rotation

Approximately 50% of the workers in the exposed group were employed in a subset of jobs requiring rotation between different lifting jobs during the day. These jobs produced sequential exposure of variable magnitude. Because no procedure was available at the time of the study for evaluating sequential exposure, workers were assigned to the job element with the greatest LI value. This likely would result in overestimation of LI, which would bias the risk estimate for LBP toward the null.

Exposure Variables

Exposure variables used in the analyses included the dichotomous exposure variable (exposed vs unexposed), the LI as a continuous variable, and the LI as a categorical variable (see exposure categories mentioned later). For purposes of this article, the LI and CLI are used interchangeably. For the categorical analysis, the LI was divided into the following five categories: LI = 0 (unexposed), $0 < LI \leq 1$, $1 < LI \leq 2$, $2 < LI \leq 3$, and $LI > 3$. These groups were chosen because, according to the developers of the lifting equation, the $0 < LI \leq 1$ group is considered to have the lowest risk and the $LI > 3$ group is considered to be at increased risk of LBP.

SYMPTOM AND OCCUPATIONAL HISTORY QUESTIONNAIRE

The questionnaire used in the second data collection study was similar to the one used in the first data collection that was previously reported. The questionnaire was self-administered and included questions about pain and discomfort in the back and other areas of the body, as well as questions about potential confounders. The questionnaire included standardized scales to assess perceived work demands, work control, social support, job satisfaction, and ability to meet production standards, which were taken from the NIOSH Generic Job Stress Survey or previous NIOSH surveys.[15] Self-reported measures of capacity as assessed by the Borg scale were also included to determine possible selection bias of workers into jobs with high LI values.[16]

The questionnaire also collected information on age, height, weight, gender, smoking status, time spent in a vehicle commuting to work, time spent sitting at work, education, plant, years in the company, years on the job, and work shift. Workers completed the questionnaire in small groups during working hours. All workers on all shifts in each of the sampled jobs were invited to complete the questionnaire.

CASE DEFINITION

Case definitions of LBP for this study are the same as was used in the previous study of the revised NLE (RNLE)[14] and are similar to case definitions used in other studies of LBP.[5,17,18] The case definitions included (1) LBP ever (BPE), (2) LBP in the last 12 months (BP12), (3) LBP due to repeated activities at work in the last 12 months (BPRA), and (4) LBP in the last 12 months due to accident at work (BPAC). The question about BPE, "Have you ever had back pain which lasted every day for a week or more?" is similar to questions about lifetime incidence posed in a number of Nordic studies.[19] The questions about BP12, "During the previous 12 months, have you had back pain everyday for a week or more"; BPRA, "Was any of this pain brought on by repeated activities, such as lifting, pushing, or bending?"; and BPAC, "During the previous 12 months, have you had back pain everyday for a week or more that resulted from an accident (such as slipping, falling, or a car accident), as well as a question about where the activity was performed that caused the LBP, are the same as questions included in the 1988 Health Interview Survey, which provides us with community-based data for comparison.[5,20] Pain and discomfort in other parts of the body was assessed using a Corlett and Bishop body part discomfort diagram but is not reported in this article.[21]

STATISTICAL METHODS

The statistical analysis methods are identical to those used in the first data collection that was previously reported,[14] so that the data from the two data collections could be combined to increase power. As before, the LI was chosen as the primary measure of worker exposure to manual lifting. Potential confounders were separated into three groups: psychosocial, personal, and demographic variables.

Logistic regression models were fitted for each group of variables. We conducted both continuous and categorical analyses of the LI but have focused on the categorical results because previous discussions have focused on the utility of specific values, such as LI values of less than 1.0 and greater than 3.0. Prevalence odds ratios (OR) were determined for each variable in the group, and the changes in the parameter estimates for the four LI categories greater than 0 (unexposed group) were examined. Prevalence proportion ratios (PPR), which are the ratio of the prevalence among the exposed to the prevalence among the unexposed were also estimated because it has been argued that in a cross-sectional study of a disease with undefined duration (like LBP), the prevalence OR is difficult to interpret and that the PPR is preferable.[22–24] Therefore, we also derived PPR estimates with a generalized linear model with logarithmic link function and binomial error distribution (a log-binomial model) using PROC GENMOD in SAS (SAS Institute, Cary, NC).[25]

As was done previously, the "demand" variable was combined with the "ability to meet production standards" variable and the social support variables were combined into one support variable. Job satisfaction and education could not be combined with other variables.

For our analysis, we only considered the LI and CLI as our exposure metric. We investigated evaluating individual factors in the NLE, but we determined that we did not have sufficient power to evaluate them accurately.

RESULTS

Demographics of Study Participants and Their LI Distribution

In this second data collection, a total of 393 additional persons (356 persons in the exposed group and 37 persons in the unexposed group) completed the questionnaire. This resulted in a total sample size for the combined analysis of 677 persons (560 in the exposed group and 117 persons in the unexposed group). The 393 additional workers included 37 workers in the LI = 0, 84 in $0 < LI \leq 1$, 107 in the $1 < LI \leq 2$, 115 in the $2 < LI \leq 3$, and 50 in the $LI > 3$ categories, respectively. Although the completion of the questionnaire was voluntary, we found no resistance to participation in any of the five plants. Approximately 80% of eligible workers invited to participate in the study completed the questionnaire. Participation rates did not differ significantly between LI categories. Participant demographics for the combined data, by LI category, are presented in Table 1. Overall, the percentage of women and older workers increased from the previous study.

Reported Health Outcomes

Overall, across the nine plants, the prevalence of reported LBP in the exposed and unexposed population, by LI category, is shown in Table 2. The prevalence of any lifetime LBP (ie, any previous LBP) is similar for all exposure categories. When the outcome is restricted to LBP lasting a week or more in the last 12 months, however, the prevalence is significantly higher for the exposed groups. The differences are greater when the outcome is associated with repeated activities at work, where 37% of workers in jobs in the $2 < LI \leq 3$ category reported BPRA, compared to only 3% in the unexposed group. In our study, 15% of the unexposed workers who reported having LBP lasting a week or more in the last 12 months believed that their LBP was because of repeated activities at work. In contrast,

TABLE 1. Study Population Demographics for Workers on Current Job During the Last 12 Months or More, by LI Category

Demographic variable	Lifting Index Category: Unexposed	Exposed			
	LI = 0	0 < LI ≤ 1	1 < LI ≤ 2	2 < LI ≤ 3	LI > 3
Mean age (yr)	46.1	35.9	40.6	39.8	41.6
Gender (M/F), %	77/23	67/33	77/23	86/14	93/7
Body mass index	27.2	27.3	27.9	27.9	28.3
Mean years at company	19.7	8.0	13.4	14.6	13.4
Mean years at current job	9.1	4.7	6.3	6.9	7.8
No. workers	117	93	143	236	88

TABLE 2. Reported Health Outcomes for Workers on Current Job During the Last 12 Months or More, by Lifting Index Category

Health outcome	Lifting Index Category: Unexposed	Exposed			
	LI = 0	0 < LI ≤ 1	1 < LI ≤ 2	2 < LI ≤ 3	LI > 3
No. workers	117	93	143	236	88
% previous back pain ever	43	43	45	53	47
% back pain in last 12 mo	22	29	34	40	30
% back pain due to repeated activities in last 12 mo	3	25	29	37	27

89% of the exposed workers who reported having BP12 believed that their LBP was due to repeated activities at work.

MULTIVARIATE ANALYSES

Prevalence Ratios

Unadjusted prevalence OR estimates for the four LI categories for the outcome measure "LBP during the last 12 months" are presented in Table 3. As the LI increases, the prevalence of LBP also increases as the LI approaches 3.0 and then drops for the LI > 3 category (0 < LI ≤ 1 [OR = 1.43], 1 < LI ≤ 2 [OR = 1.82], 2 < LI ≤ 3 [OR = 2.32], LI > 3 [OR = 1.47]). Previously, the 1 < LI < 2 category was not significantly different from the unexposed group and only the OR for the 2 < LI < 3 category was significantly greater than the unexposed group. The additional power provided by adding individuals to the study across all exposure levels, however, has now shown that the OR for the 1 < LI ≤ 2 category is also significantly higher than the unexposed group. The *P* value for the test for trend for the LI treated, as either a categorical or continuous variable is 0.02. Odds ratios based on a model adjusted for age, gender, and body mass index were evaluated and found to be similar to those estimated from the unadjusted model.

TABLE 3. Unadjusted Prevalence OR and PPR for Reporting LBP During the Last 12 Months as a Function of the Lifting Index*

Variable	OR	95% CI	PPR	95% CI	*n*
LI = 0	1.00	Reference	1.00	Reference	117
0 < LI ≤ 1	1.43	0.76–2.68	1.31	0.82–2.09	93
1 < LI ≤ 2	1.82	1.05–3.21	1.54	1.04–2.36	143
2 < LI ≤ 3	2.32	1.41–3.9	1.79	1.26–2.67	236
LI > 3	1.47	0.78–2.77	1.33	0.83–2.14	88

CI, confidence interval; LI, lifting index; OR, odds ratios; PPR, prevalence proportion ratio.
*$P = \sim 0.02$ for a trend analysis when evaluated as a categorical or a continuous variable. Population included 677 persons with more than 12 months on the job.

Table 3 also displays the unadjusted PPR estimates for the four LI categories. The health outcome pattern and *P* values for the PPR model are similar to the OR model, but the magnitude of the values are lower, as was shown in the previous study.

The unadjusted prevalence OR estimates for the four LI categories for the outcome measure "LBP due to repeated activities at work" for the overall data analysis are displayed in Table 4. The differences between the exposed and unexposed categories are even more dramatic for this outcome measure. As the LI increases, the prevalence of LBP also increases as the LI approaches 3.0 and then drops for the LI > 3 category (0 < LI ≤ 1 [OR = 9.28], 1 < LI ≤ 2 [OR = 11.36], 2 < LI ≤ 3 [OR = 16.49], LI > 3 [OR = 10.59]). The unadjusted PPR values for this outcome measure are similar to the OR values, but somewhat smaller in magnitude (0 < LI ≤ 1 [PPR = 7.23], 1 < LI ≤ 2 [PPR = 8.39], 2 < LI ≤ 3 [PPR = 10.78], LI > 3 [PPR = 7.98]).

CONFOUNDERS

As previously mentioned, certain psychosocial variables were collapsed into single indices using factor analysis. Perceived work demands and ability to meet production standards were collapsed into one factor, and all the social support items were collapsed into one factor.

Prevalence OR and PPR estimates for the four LI categories, adjusted for psychosocial and personal variables, are shown in Table 5. Job satisfaction was the only confounder found to be statistically significant in the multivariate analysis. This is consistent with the findings from the previous study.[14] As can be seen in Tables 3 and 5, the differences in the OR estimates for the LI categories between the unadjusted and adjusted models are not very large. The LI category 1 < LI ≤ 2, however, was not significant in the adjusted model, whereas it was significant in the unadjusted model.

DISCUSSION

Since the inception of the RNLE, several studies have found significant associations between the LI and the prevalence of reported back disorders.[10,14,26,27] These studies showed that the LI was able to predict whether a job had significantly increased risk for workers to report LBP. In one study, Marras et al[10] showed that the LI could predict the probability of high-risk group membership for LBP. In another study of 97 manual materials handling jobs, a significant positive correlation between the LI and severity of low back discomfort was found.[26] In yet another study examining the original (1981) NLE, the LI was found to be predictive of risk of low back injury.[27] Finally, in another cross-sectional epidemiological study of manual lifting jobs, researchers showed that the LI was predictive of

TABLE 4. Unadjusted Prevalence OR and PPR for Reporting Low Back Pain Because of Repeated Activity at Work During the Last 12 Months as a Function of the Lifting Index*

Variable	OR	95% CI	PPR	95% CI	*n*
LI = 0	1.00	Reference	1.00	Reference	117
0 < LI ≤ 1	9.28	3.40–32.65	7.23	2.91–24.03	93
1 < LI ≤ 2	11.36	4.39–38.76	8.39	3.52–27.32	143
2 < LI ≤ 3	16.49	6.63–55.12	10.78	4.65–34.66	236
LI > 3	10.59	3.88–37.25	7.98	3.23–26.42	88

CI, confidence interval; OR, odds ratios; PPR, prevalence proportion ratio.
*$P < 0.001$ for a trend analysis when evaluated as a categorical or a continuous variable. Population included 677 persons with more than 12 months on the job.

TABLE 5. Prevalence OR and PPR for Reporting Low Back Pain During the Last 12 Months as a Function of Lifting Index, adjusted for age, gender, BMI, and Psychosocial Factors*

Variable	OR	95% CI	PPR	95% CI	*n*
LI = 0	1.00	Reference	1.00	Reference	117
0 < LI ≤ 1	1.08	0.54–2.17	1.15	0.72–1.85	93
1 < LI ≤ 2	1.22	0.65–2.32	1.16	0.76–1.81	120
2 < LI ≤ 3	1.88	1.07–3.36	1.48	1.02–2.23	197
LI > 3	1.36	0.68–2.72	1.32	0.83–2.10	79
Demand and ability to meet work requirements (continuous)	1.20	0.96–1.50	1.08	0.94–1.25	
Control (continuous)	1.00	0.81–1.24	1.01	0.89–1.15	
Support (continuous)	1.23	0.91–1.66	1.16	0.96–1.39	
Somewhat satisfied†	1.72	1.07–2.81	1.50	1.06–2.19	
Not too satisfied†	2.90	1.54–5.49	2.08	1.40–3.15	
Not at all satisfied†	5.90	1.99–19.20	2.24	1.31–3.73	
Gender (woman)	0.97	0.57–1.61	0.99	0.72–1.30	
Age (continuous)	0.99	0.97–1.00	1.00	0.98–1.00	
BMI (continuous)	0.97	0.94–1.01	0.98	0.96–1.01	

BMI, body mass index; CI, confidence interval; OR, odds ratios; PPR, prevalence proportion ratio.
*Population included 606 persons with more than 12 months on the job (one company's data were excluded because of missing data).
†OR for comparison with "very satisfied" condition.

LBP and that the risk of LBP was significantly increased when the LI value exceeded a value of 2.0.[14] This article reports on an analysis of combined data from two data collections, the first reported by Waters et al,[14] and a second data collection with additional data from new sites and new jobs that has strengthened our understanding of the "dose–response" relationship between the LI and reported LBP. The combined analysis shows that the risk of reported LBP increased significantly as the LI value increased in a range from 1.0 to 3.0. The findings from these studies support the conclusion that the NLE can be used to identify lifting jobs with increased risk of LBP. One of the important proposed applications of the lifting equation is as a tool for estimating the percentage of the population that is likely to be at risk for developing lifting-related LBP. It has been suggested that most of the working population should be able to perform jobs with LI values less than 1.0 without a significant risk of LBP, and that the risk would begin to increase as the LI exceeds 1.0. When examining the combined data, we found a statistically significant trend in the relationship between the prevalence of LBP and the LI as shown in Tables 3, 4, and 5, with a peak unadjusted OR of 2.32 and a PPR of 1.79 in the $2 < LI \leq 3$ category for the outcome of BP12 and an OR of 16.49 and a PPR of 10.78 in the $2 < LI \leq 3$ category for the outcome of BPRA. Previously, we had not shown the $1 < LI \leq 2$ category to be statistically different from the non-exposed group. The results from the analysis of the combined data now show a statistically significant trend in the relationship between the prevalence of LBP and LI for the $1 < LI \leq 2$. On the basis of the analysis of the combined data, we showed that a peak unadjusted OR of 1.82 and a PPR of 1.54 in the $1 < LI \leq 2$ category for the outcome of BP12 and an OR of 11.36 and a PPR of 8.39 in the $1 < LI \leq 2$ category for the outcome of BPRA were significantly different from the unexposed group. These findings mean that it was more than twice as likely for a worker to report LBP lasting a week or more in the last 12 months if they worked in a job with an LI value between 2.0 and 3.0 compared with those who worked in a nonlifting job. It also means that workers were more likely to report that their LBP was due to repeated activities at work compared with workers who were not required to perform lifting tasks in their jobs (more than 10 times more likely).

As we found in the first data collection,[14] the risk in the highest exposure group (ie, LI > 3), was less than in the $2 < LI \leq 3$ group. As we noted previously,[14] it is possible that this may be due to problems with the predictive power of the equation. This is not likely the case, however, but probably due to a combination of "worker selection" and "survivor" effects. Selection of stronger workers into jobs with high physical demands is quite common, even when a specific worker selection program is absent. Moreover, there is also the potential for a survivor effect, in which certain individuals with high tolerance for heavy manual lifting can continue to work in jobs with high physical demands, whereas workers with lower tolerances may have to leave the job. Both of these effects can bias risk estimates of LBP toward the null, especially for those jobs with high physical demands, such as those with an LI value greater than 3.0. Support for a survivor effect can be seen in Table 1, where it can be observed that the mean number of years on the current job increases as the LI category increases. This may indicate that for the populations included in this study, as the LI value increases, workers with lower tolerance to the physical demands of a job leave to find a new job, whereas workers with higher tolerance stay. This effect was previously shown in a longitudinal epidemiological study of sewing machine operators, in which Schibye et al[28] reported that individuals who left the job of sewing machine operator to take another job had a higher prevalence of musculoskeletal disorders than those remaining on the job.

Another possible explanation for the reduced prevalence rates in some of the jobs in the LI > 3 category, which has been shown in previous studies, could be high turnover rates. In a study of worker turnover rates on physically demanding jobs, Lavender and Marras[29] showed that turnover rate was a good indicator of high risk for LBP. They attributed the lower than expected injury rates to the "healthy worker effect," previously described by Andersson.[30] That is, workers at high risk of injury may leave the job rather than wait until an injury occurs, thereby lowering the overall incidence rate for that job. Unfortunately, we did not obtain data regarding turnover rate in either data collection.

With respect to LBP prevalence, the results of this study are similar to results found in previous studies. In this study, 32% of the study population reported having LBP lasting a week or more in the last 12 months. In comparison, 17.6% of respondents in the 1988 Health Interview Survey, a large community-based investigation of occupational health, reported having LBP lasting a week or more in the last 12 months.[5,20]

In a previous 1988 survey,[20] the prevalence rates for the highest risk occupations for work-related LBP for men were 22.6% for male construction laborers, 22.2% for carpenters, and 21.8% for truck and tractor equipment operators. For women, the prevalence rates for the highest risk occupations for LBP were 18.8% for nursing aides, orderlies, and attendants, 16.3% for licensed practical nurses and 14.9% for maids.[5,20] Finally, our lifetime prevalence rates for LBP (47%) were somewhat lower than those found in previous studies of LBP in the Nordic population (between 60% and 65%).[19] Our lower rates may be due to differences in the case definition.

In our analysis of the overall data, when asked about the cause of LBP, only 3% of the unexposed group and 89% of the exposed group attributed their LBP to repeated activities at work, a dramatic difference. In fact, the OR was between 9.28 and 16.49 for the exposed groups compared with the unexposed group. Some would argue that it is not appropriate to report the OR values for this outcome measure because the exposed groups were purposely selected to have repeated lifting activities. It is worth noting, however, that the perception of the workers is that their LBP is due to repeated activities at work, presumably the repeated lifting tasks they were required to perform.

In addition to the LI, job satisfaction was the only variable shown to be significantly related to worker-reported LBP. The finding is in agreement with literature examining the effects of psychosocial risk factors for LBP.[14,31,32] With a cross-sectional study design, however, it is not clear whether job dissatisfaction could be a cause of higher reporting of LBP, or conversely, whether increased occurrence of back pain could be a cause of higher reporting of job dissatisfaction. In the past two decades, several longitudinal studies were conducted to investigate the role that job satisfaction plays in the development of LBP. Two recent literature reviews on psychosocial risk factors for work-related musculoskeletal disorders suggest that among many psychosocial factors, job satisfaction was found to have moderate to strong evidence of a casual relationship with LBP.[8,33] Little is known, however, as to the causal mechanisms of job satisfaction and LBP. It is likely that job satisfaction interacts with other social and individual factors to influence spinal loading during manual materials handling. For example, in a recent study examining risk factors for reported LBP, Waters et al[17] reported that exposure to either "heavy lifting" or "work stress" alone resulted in an OR of 1.9 for either factor alone, but when the exposure included both "heavy lifting" and "work stress" in combination, the OR was 4.5, clearly an additive relationship. It is likely that work stress is related to job dissatisfaction in some way and affects the way the worker performs the work task. Job satisfaction seemed to play a larger role in the adjusted model compared with the unadjusted model and the effect seemed to be larger than for the LI. It should be noted that it is unclear whether job satisfaction is an outcome of LBP or that workers who are dissatisfied are more likely to report LBP than workers who are more satisfied with their work. Finally, longitudinal research with robust quantifications of all the risk factors for LBP likely would contribute to the knowledge gap.

STUDY LIMITATIONS

As with all cross-sectional studies, selection bias may have caused an underestimation of LBP rates, particularly in the high exposure group (LI > 3.0). Because our criteria for inclusion in the study required a worker to have been in the current job for at least 12 months, those workers who found that a job exceeded their physical capability may have left that job after a brief time. The results of this bias should lead to an underestimation of the dose–response association between LI and LBP. Second, our unexposed population includes many office workers who may work most of the day in a seated posture. Because studies have shown a relationship between LBP and sustained use of the seated posture, their rates of LBP may be higher than a truly unexposed population. This also would result in a bias of the results toward the null.

One commonly recognized limitation of occupational exposure assessment is accounting for the naturally occurring variability in exposure that exists in many jobs. In this study, we handled the variability in a variety of ways. When appropriate, we used the NIOSH multitask method to account for known variability. In some cases, however, the multitask method cannot be used because of difficulty in determining the distribution of the variability. For those jobs, we chose to use the worst case characteristics to compute the LI values. We recognize that more detailed methods of accounting for variability may be needed to refine our risk-assessment capability. Nonetheless, in this case, our decision to choose the worst case would bias our results toward the null.

It should be noted that the findings from this study are applicable only for jobs meeting the selection criteria listed in the methods section. It is not clear how applicable the NIOSH equation would be for jobs with unpredictable variation in task characteristics or for jobs with lifting exposures combined with exposure to whole body vibration, or for jobs that do not meet the constraints of the RNLE.

The companies who agreed to participate in this study have been proactive in applying ergonomics before our study and have made great strides in incorporating ergonomics into their job designs. For this reason, it was not unexpected that most of the jobs had LI values less than 3.0. Also, there is a possibility that the jobs we evaluated would not be representative of jobs we may have found in other workplaces, which may result in a differential bias of risk in either direction.

Finally, comparing the results of this study with others that have investigated the work-relatedness of LBP presents some difficulties. Studies of low back disorders have used a variety of health outcome measures, including self-reported LBP, OSHA 300 Logs, worker's compensation records, days lost, restricted duty, etc. The various outcome measures may reflect differences in the clinical severity of the disorder, ranging from early symptoms to impairment and finally disability and compensation. No single outcome measure is better than the others because each measure has both strengths and weaknesses. For example, there are inconsistencies in how companies report low back disorders. Some companies offer incentives for not reporting problems, resulting in unreported cases of LBP. Also, many of these measures fail to capture those individuals who move into restricted duty or change jobs because of low back problems. Similarly, there are differences between workers compensation claims from state to state. For this reason, it is difficult to compare many of the epidemiological studies that have been undertaken in the past.[34]

CONCLUSIONS AND RECOMMENDATION FOR FUTURE RESEARCH

First, even though LBP is a common disorder, analysis of the results indicates that the LI is a useful indicator of jobs with high risk of LBP due to manual lifting. Specifically, our findings indicate that a worker who continuously performs a manual lifting job with a LI greater than 1.0 is at a significantly increased risk of having LBP lasting a week or more during any 12-month period than a worker in a nonlifting job. The risk is increased when the LI is between 2.0 and 3.0. Moreover, as the LI increases, workers with LBP are more likely to believe that their LBP is due to the repeated activity that they do on the job.

Second, although additional data are needed, our findings indicate that personal and psychosocial factors did not have a significant effect on reports of LBP in this study. Because of the uncertainty of the temporal relationship between reported job dissatisfaction and LBP, however, it is difficult to determine whether job dissatisfaction was a result of LBP or whether increased reporting of LBP was a result of job dissatisfaction. In either case, excessive job demands were associated with increased rates of reported LBP.

This study demonstrates that the LI is a useful predictor of risk of lifting-related LBP. Also, more research is needed to investigate the possible effects of psychosocial and personal factors on the reports of LBP, which have been shown in other studies. Finally, research is needed to refine and extend the application of the RNLE to encompass a wider range of lifting jobs, such as those involving one-handed lifting, lifting in combination with pushing, pulling and carrying, lifting in less than optimal environmental conditions, and jobs with variable task characteristics.

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