Reprinted from SPINE, Vol. 24, No. 4, February 15, 1999

Printed in the U.S.A.

Evaluation of the Revised NIOSH Lifting Equation

A Cross-Sectional Epidemiologic Study

Thomas R. Waters, PhD, Sherry L. Baron, MD, MPH, Laurie A. Piacitelli, MS,
Vern P. Anderson, PhD, Torsten Skov, PhD, Marie Haring–Sweeney, PhD,
David K. Wall, MAS, and Lawrence J. Fine, MD, DrPH

SPINE Volume 24, Number 4, pp 386–395
©1999, Lippincott Williams & Wilkins, Inc.

Evaluation of the Revised NIOSH Lifting Equation

A Cross-Sectional Epidemiologic Study

Thomas R. Waters, PhD, Sherry L. Baron, MD, MPH, Laurie A. Piacitelli, MS, Vern P. Anderson, PhD, Torsten Skov, PhD, Marie Haring–Sweeney, PhD, David K. Wall, MAS, and Lawrence J. Fine, MD, DrPH

Study Design. A cross-sectional study of the 1-year prevalence of low back pain was conducted in workers employed in manual lifting jobs.

Objectives. To provide epidemiologic data to determine the correlation between the prevalence of low back pain and exposure to manual lifting stressors, measured with the lifting index component of the revised lifting equation from the National Institute for Occupational Safety and Health (NIOSH).

Summary of Background Data. The NIOSH lifting equation has been proposed as a practical, yet valid tool for assessing the risks of low back pain caused by manual lifting. To date, however, there have been few studies in which the effectiveness of the equation to identify jobs with elevated rates of low back pain has been evaluated.

Methods. Fifty jobs from four industrial sites were evaluated with the NIOSH lifting equation. A symptom and occupational history questionnaire was administered to 204 people employed in lifting jobs and 80 people employed in nonlifting jobs. Regression analysis was used to determine whether there was a correlation between the lifting index and reported low back pain.

Results. As the lifting index increased from 1.0 to 3.0, the odds of low back pain increased, with a peak and statistically significant odds ratio occurring in the $2<\text{lifting index}\leq 3$ category (odds ratio = 2.45). For jobs with a lifting index higher than 3.0, however, the odds ratio was lower (odds ratio = 1.45).

Conclusions. Although low back pain is a common disorder, the lifting index appears be a useful indicator for determining the risk of low back pain caused by manual lifting. [Key words: dose response, low back pain, manual lifting, risk assessment] **Spine 1999;24:386–395**

There is substantial interest in identifying hazardous lifting tasks because low back pain (LBP) continues to affect a large percentage of workers. In 1988 alone, back disorders in the United States accounted for approximately 25% of all lost workdays (half a billion lost workdays) with 22 million cases reported that year.[10] It is estimated that as many as 30% of the American workforce regularly perform potentially hazardous material handling as a part of their jobs.[19] The economic costs attributable to low back disorders are staggering. In 1989, the average cost of a workers' compensation claim for LBP was reported to be $8321, which was more than twice the average for all compensable claims combined ($4075).[25] Investigators estimated the total compensable cost for LBP in the United States in 1989 to be $11.4 billion. Many back disorders have been linked to specific high-risk occupational lifting activities that cause excessive biomechanical and physiologic loading on the workers.[9,17,18]

In response to this serious 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. The analysis tool consists of two equations, the recommended weight limit (RWL) and the lifting index (LI), for evaluating a specified manual lifting task (equations listed in Appendix A). 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 (L) lifted divided by the RWL for the job (LI = L/RWL). A description of the criteria and rationale used to develop the RWL and LI was published by Waters et al in 1993.[22]

The purpose of this study was to provide epidemiologic data to define the correlation between the LI and the prevalence and severity of lifting-related LBP. The study was envisioned as one in a series of several epidemiologic studies to evaluate this important correlation.

■ Methods

Study Description. The main elements of the study included:

- selection of manual lifting jobs (exposed) at four companies;
- selection of control or nonlifting jobs (unexposed) at each plant;
- measurement of data needed to calculate the RWL and LI for each of the selected jobs;
- and completion of a self-administered questionnaire by workers in each of the exposed and unexposed jobs.

Selection of Study Sites and Jobs. Four industrial facilities with a wide range of manual lifting jobs volunteered to participate in the study. Lifting jobs were selected for inclusion in the study based on observations of representative workers and through discussions with plant personnel. The NIOSH investigators were blinded to back pain or injury rates for all jobs. The

---

From the National Institute for Occupational Safety and Health, Cincinnati, Ohio.
Acknowledgment date: October 28, 1997.
First revision date: February 12, 1998.
Acceptance date: May 5, 1998.
Device status category: 1.

criteria used for selecting jobs for inclusion in the exposed or lifting group were:

- jobs in which manual lifting is performed as a regular daily task activity, with at least 25 lifts per day;
- jobs with no major changes in content, pace, and work practices for the past 2 years;
- jobs with little or no unpredictable variations in task characteristics;
- jobs that complied with the application criteria of the RWL.[23] (That is, none involved one-handed or 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 involved shifts lasting up to 12 hours);
- jobs that did not involve exposure to significant whole-body vibration (*e.g.*, driving a truck more than 4 hours a day).

Fifty lifting jobs were included in the study. Of the 50 jobs, 22 were located at a diesel engine manufacturing plant where workers performed various machining and assembly operations of prefabricated parts weighing between 14 and 64 lb. The machining jobs typically required workers to lift parts repetitively between storage bins and drilling and surfacing machines. The assembly jobs consisted of workers lifting parts from storage bins and attaching them to the engine, which was either stopped or moving on a conveyor. Another six jobs were located at a fiberglass insulation manufacturing plant where workers performed handling activities common in a warehouse, in which bundles or bags of fiberglass insulation are lifted from a machine or conveyor to a cart or conveyor for packaging or shipment. The bundles typically weighed 19–45 lb. Another five jobs were located at a printing plant where workers performed lifting activities in the bindery department. The main job of these workers was to feed pages into binding machines and then box the finished product. One of the jobs in the bindery department required lifting either a 55-lb or 88-lb bundle of paper from floor height to a position approximately 3.5 ft from the floor. Finally, 17 lifting jobs were located at an appliance manufacturing plant, where workers performed light manufacturing, painting, and assembly jobs and were required to lift parts from stamping machines, off of conveyors, or out of racks or bins for assembly or preparation for assembly. The weights of items lifted at the appliance manufacturing plant ranged between 5 and 48 lb.

Workers included in the unexposed group were typically employed in office-related jobs that did not require lifting. Workers in the unexposed group were excluded from the study, however, if they reported heavy pushing or pulling more than 10 times a day, lifting 25 pounds or more 10 times a day or more, or lifting 50 pounds even once a day. Thus, the exposed population was defined as those who performed the 50 selected jobs, and the unexposed population was defined as a group of workers with no significant exposure at the time of the study to 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 personnel trained to make the measurements in a standardized manner. It has been shown that reliable measurements are obtained if standardized measurement methods are used.[24] Workers were observed and interviewed to identify individual tasks within the job and to document the task times and work station layout. The following data were collected for each selected job to calculate the RWL and LI: weight of the object lifted, duration of the task 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, and, if the task required lifting from the side of the body, the angle of asymmetry at the origin and destination of the lift in degrees. A sample of workers doing each of the exposed jobs was observed and analyzed during a 2–4-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 on 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 NIOSH lifting equation allows for the computation of a composite lifting index (CLI), so 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.[23]

Calculation of Recommended Weight Limit and the Lifting Index. To reduce measurement bias in the calculations, averages were taken across all samples for all measurements to compute the LI and CLI for each job. For jobs with variability in one or more factors because of the design of the job, such as those in which the vertical height or horizontal distance at the origin or destination varied from lift to lift, a minimum and maximum LI or CLI value was computed for a worst-case and best-case assessment. Only the worst-case values were used for risk modeling. This approach was adopted for three reasons: There is no procedure available for computing the LI for jobs with extreme variability; insufficient data were collected showing the distribution of the variability, making it impractical to determine an LI based on mean lifting characteristics; and, the approach would result in an overestimate of the risk rather than an underestimate, thereby biasing the results toward the null. In a few cases, there were significant differences between data samples (*i.e.*, when the differences in measurements would result in more than a 5–10% difference in the LI or CLI value). In these cases, a professional ergonomist reviewed the video tape of the job, simulated the lifting task, and judged what the appropriate measurements should be for the computations.

The measured horizontal distance (H) exceeded the 25-in. maximum limit set by NIOSH for 30% of the jobs. For purposes of this study, H was set to equal 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 can not be used to distinguish between jobs. Second, in nearly all cases in which H exceeded 25 in., workers leaned over and centered their weight over one foot rather than centering 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 approximately 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 34% of the exposed group of workers were employed in a small fraction of jobs (6%) requiring rotation between different lifting jobs during the day. These jobs produced sequential exposure of variable magnitude. Because there is no procedure currently available for evaluating sequential exposure, workers were assigned to the job element with the greatest LI value. This could 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 below). 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), LI between 0 and 1, LI between 1 and 2, LI between 2 and 3, and LI>3. These groups were chosen because, according to the lifting equation, the $0<\text{LI}\leq 1$ group was considered to have the lowest risk and the LI>3 group was considered to have the highest risk.

Symptom and Occupational History Questionnaire. 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.[11] Self-reported measures of capacity, assessed by the Borg scale, were also included to determine possible selection bias of workers performing jobs with high LIs.[6]

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 plant, 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. In all of the plants, more than 80% of the invited workers agreed to complete the questionnaire.

Case Definition. Case definitions of LBP for this study are similar to case definitions used in other studies of LBP. The case definitions included: (1) back pain ever (BPE), (2) back pain in the past 12 months (BP12), (3) back pain in the past 12 months caused by repetitive activities at work (BPRA), and (4) back pain in the past 12 months because of accident at work (BPAC). The question about BPE, "Have you ever had back pain that lasted every day for a week or more?" is similar to questions about lifetime incidence posed in a number of Nordic studies.[14] The questions about BP12, "During the previous 12 months, have you had back pain every day for a week or more"; BPRA, "Was any of this pain brought on by repetitive activities, such as lifting, pushing or bending?"; and, BPAC, "During the previous 12 months, have you had back pain every day 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 back pain, are the same as questions included in the 1988 Health Interview Survey, which provides us with community-based data for comparison.[3,10] Pain and discomfort in other parts of the body were assessed using a Corlett and Bishop body-part discomfort diagram, but these data are not reported in this article.[7]

Statistical Methods. The LI was chosen as the primary measure of worker exposure to manual lifting. Potential confounders were separated into three groups representing psychosocial, personal, and demographic variables. Logistic regression models were fitted for each group of variables. Continuous and categorical analyses of the LI were conducted, but the focus was on categorical results because previous discussions have focused on the utility of specific LIs, such as 1 and 3. Prevalence odds ratios were determined for each variable in the group, and the changes in the parameter estimates for the four LI categories above 0 (unexposed group) were examined. Prevalence proportion ratios (PPR), which are ratios of the prevalences among the exposed to the prevalences among the unexposed were also estimated, because it has been argued that in a cross-sectional study of a disease with undefined duration, such as back pain, the prevalence odds ratio is difficult to interpret, and that the PPR is preferable.[2,15] Therefore, PPR estimates were also derived with a generalized linear model with logarithmic link function and binomial error distribution (a log-binomial model) using commercial software (Prog Genmod; SAS, Cary, NC).[20]

Factor analysis was used to determine whether the potential confounders could be collapsed into a smaller number of variables. Based on the factor analysis, 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.

■ Results

Three hundred eight people completed the questionnaire. Although the completion of the questionnaire was voluntary, no resistance to participation was encountered in any of the four plants. Among the unexposed workers, between 82% and 100% of current workers completed the questionnaire in the four facilities. In the exposed jobs, between 89% and 95% of the current workers completed the questionnaire. Participation rates did not differ significantly between LI categories. Because the primary outcome measure was presence of LBP during the previous 12 months, people with less than 12 months on the job were excluded, leaving a total of 204 people in the exposed group and 80 people in the unexposed group.

Participant demographics, by LI category, are presented in Table 1. Overall, exposed and unexposed

Table 1. Study Population Demographics for Workers on Current Job ≥1 Year, by Lifting Index (LI) Category

Demographic Variable	Lifting Index Category				
	Unexposed ($LI = 0$)	Exposed			
		$0 < LI \leq 1$	$1 < LI \leq 2$	$2 < LI \leq 3$	$LI > 3$
Mean age (yr)	46.3	39.2	44.2	40.5	44.1
Gender (%M/%F)	76/24	56/44	89/11	84/16	100/0
Body mass index	27.0	25.9	28.8	28.2	28.4
Mean time at company (yr)	20.6	7.2	16.0	14.3	20.0
Mean time at current job (yr)	8.6	4.8	6.1	7.1	10.8
No. of workers	80	9	36	121	38

workers at the diesel manufacturing plant and the printing plant were older than workers at the other two sites, and workers at the printing plant had the longest tenure on the current job.

Recommended Weight Limit and Lifting Index Results

A summary of the results of the evaluation with the revised NIOSH Lifting Equation by LI category for the 50 jobs included in the analysis is provided in Table 2. Lifting indexes among the 50 jobs ranged between 0.4 and 4.6, with mean values of 0.6, 1.6, 2.6, and 3.7 in the $0<LI\leq1$, $1<LI\leq2$, $2<LI\leq3$, and $LI>3$ groups, respectively. The single-task analysis procedure was used for 41% of the jobs, and the multitask analysis procedure was used for the remaining 59%.

Reported Health Outcomes

The prevalence of reported LBP in the exposed and unexposed population by LI category is shown in Table 3. The prevalence of any lifetime LBP (*i.e.*, previous LBP) was similar in all exposure categories. When the outcome was restricted to LBP lasting a week or more in the past 12 months, however, the prevalence was highest in the $2<LI\leq3$ category. The differences were greater when the outcome was associated with repetitive activities at work, where 34% of workers in jobs in the $2<LI\leq3$ category reported LBP in the past 12 months caused by repetitive activities at work, compared with only 5% in the unexposed group. Four of 16 (25%) of the unexposed workers who reported having LBP lasting a week or more in the past 12 months thought that their back pain was caused by repetitive activities at work. In contrast, 62 (90%) of 69 of the exposed workers who reported having LBP in the past 12 months thought that their back pain was caused by repetitive activities at work.

Multivariate Analyses

Prevalence Ratios. Unadjusted prevalence odds ratio (OR) estimates in the four LI categories are presented in Table 4. As the LI increased, the prevalence of LBP also increased until the LI exceeded 3.0 and then decreased in the $LI>3$ category ($0<LI\leq1$ OR = 1.14; $1<LI\leq2$ OR = 1.54; $2<LI\leq3$ OR = 2.45; and $LI>3$ OR = 1.63). Except in the $2<LI\leq3$ group, the size of the exposure groups was small, and therefore, only the OR in the $2<LI\leq3$ group was statistically significant. $P = 0.09$ in the test for trend for the LI when treated as a categorical variable, and $P = 0.05$ when treated as a continuous variable. 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.

The unadjusted PPR estimates in the four LI categories are also shown (Table 4). The health outcome pat-

Table 2. Mean (Standard Deviation) Lifting Equation Values for Jobs with Workers on Current Job ≥1 Year, by Lifting Index (LI) Category

Job Variable	Lifting Index Category			
	Exposed			
	$0 < LI \leq 1$	$1 < LI \leq 2$	$2 < LI \leq 3$	$LI > 3$
No. of Jobs	6	18	19	7
Recommended weight limit	16.0 (6.2)	14.9 (7.1)	14.4 (7.2)	12.2 (3.6)
Mean lifting index	0.60 (0.21)	1.6 (0.30)	2.6 (0.26)	3.7 (0.75)
Weight	10.1 (4.7)	24.5 (14.5)	38.4 (21.0)	46.3 (22.6)
Horizontal multiplier	0.64 (0.12)	0.50 (0.12)	0.52 (0.12)	0.49 (0.13)
Vertical multiplier	0.89 (0.13)	0.89 (0.08)	0.89 (0.08)	0.86 (0.05)
Distance multiplier	0.92 (0.03)	0.96 (0.05)	0.95 (0.05)	0.94 (0.06)
Asymmetric multiplier	0.97 (0.07)	0.91 (0.09)	0.90 (0.10)	0.85 (0.11)
Coupling multiplier	0.98 (0.04)	0.99 (0.03)	0.98 (0.04)	0.98 (0.03)
Frequency multiplier	0.70 (0.10)	0.74 (0.13)	0.71 (0.20)	0.77 (0.14)

See Appendix A for multiplier descriptions.

Table 3. Reported Health Outcomes for Workers on Current Job ≥1 Year, by Lifting Index (LI) Category

Health Outcome	Unexposed (LI = 0)	Exposed 0 < LI ≤ 1	Exposed 1 < LI ≤ 2	Exposed 2 < LI ≤ 3	Exposed LI > 3
No. of workers	80	9	36	121	38
% previous BP	46	38	43	48	53
% BP in last 12 mo	20	22	28	38	29
% BP due to repeated activities in last 12 mo	4	22	25	34	26
% workers missed work due to BP from repeated activities in last 12 mo	0	0	3	18	13
Mean days lost work due to BP from repeated activities	0	0	0	31 (N = 20)	36 (N = 4)

BP = back pain.

tern and *P* values in the PPR model are similar to those in the the OR model.

Confounders. As previously mentioned, certain psychosocial variables could be collapsed into single indexes 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 odds ratio (OR) estimates in 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. The differences in the odds ratio estimates in the LI categories between the unadjusted and adjusted models are not significant (Tables 4 and 5).

■ Discussion

Although the RWL and LI equations are derived from substantial research in the areas of biomechanics, work physiology, and psychophysics, research efforts to evaluate the revised NIOSH lifting equation have been limited. To date, we have found a single retrospective epidemiology study in which attempts were made to link the risk of back pain or injury, defined by the LI component of the revised NIOSH lifting equation, with the incidence and severity of low back disorders.[17] The results in that study indicated that the new equation could predict the probability of high-risk group membership. In a previous study, the original (1981) NIOSH lifting equation was shown to be predictive of risk of low back injury.[16] The results of these studies support the conclusion that the NIOSH lifting equation can be used to identify stressful lifting tasks, which is in agreement with the results of the current study.

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 LIs less than 1.0 without a significant risk of LBP and that the risk begins to increase as the LI exceeds 1.0. In the current study, there was a statistically significant trend in the correlation between the prevalence of LBP and the LI (Tables 4 and 5) with a peak PPR of 1.9 in the $2<LI\leq3$ category. This means workers were nearly twice as likely to report LBP lasting a week or more in the past 12 months if they worked in jobs with LIs between 2.0 and 3.0 than if they worked in nonlifting jobs. Considering that LBP is a common disorder, the estimated ORs and PPRs for the groups with LIs higher than 2.0 are high. The shape of the risk curve in the LI less than 2.0 range provides extremely important information about job designs to protect most of the population from work-related LBP. Because the precision of the risk estimate for the groups with LIs less than 2.0 was low in the current study, the shape of the risk curve for these lower exposure groups was less certain. Therefore, it is

Table 4. Unadjusted Prevalence Odds Ratio (OR) and Prevalence Proportion Ratio (PPR) for Reporting Low Back Pain During the Last 12 Months as a Function of the Lifting Index (LI)

Variable	OR	95% CI	PPR	95% CI	n
LI = 0	1.00	Reference	1.00	Reference	80
0 < LI ≤ 1	1.14	0.16–5.29	1.11	0.20–3.14	9
1 < LI ≤ 2	1.54	0.60–3.80	1.39	0.67–2.72	36
2 < LI ≤ 3	2.45	1.29–4.85	1.90	1.19–3.24	121
LI > 3	1.63	0.66–3.95	1.45	0.72–2.79	38

CI = confidence interval.

P = 0.09 for trend when evaluated as a categorical variable and *P* = 0.05 when evaluated as a continuous variable. Population included 284 persons with more than 12 months on the job.

Table 5. Prevalence Odds Ratios (OR) for Reporting Low Back Pain During the Last 12 Months as a Function of Lifting Index (LI), Adjusted for Age, Gender, BMI, and Psychosocial Factors

Variable	OR	95% CI	n
$LI = 0$	1.00	Reference	80
$0 < LI \le 1$	1.04	0.13–5.84	9
$1 < LI \le 2$	1.96	0.69–5.53	36
$2 < LI \le 3$	2.20	1.01–4.96	121
$LI > 3$	1.09	0.37–3.10	38
Demand and ability to meet work requirements (continuous)	1.06	0.75–1.49	
Control (continuous)	1.02	0.73–1.42	
Support (continuous)	1.32	0.85–2.07	
Somewhat satisfied*	1.17	0.55–2.59	
Not too satisfied*	4.57	1.74–12.6	
Not at all satisfied*	7.65	1.59–45.0	
Gender (female)	1.61	0.69–3.70	
Age (continuous)	0.99	0.96–1.02	
BMI (continuous)	0.96	0.89–1.03	

CI = confidence interval; BMI = body mass index.
* OR for comparison with "very satisfied" condition.
$P = 0.27$ for overall trend. Population included 284 persons with more than 12 months on the job.

particularly important in future studies to increase the size of these groups.

In this study, the risk in the highest exposure group (*i.e.*, LI >3), was less than in the $2<LI\le3$ group. It is possible that this is the result of problems with the predictive power of the equation, although it is more likely to result from a combination of worker selection and a survivor effect. Selection of stronger workers performing jobs with high physical demands is common, even when a specific worker selection program is absent. Moreover, there is also the potential for a survivor effect, in which certain people 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 in those jobs with high physical demands, such as those with an LI higher 3.0. Support for a survivor effect can be seen in Table 1, in which 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 epidemiologic study of sewing machine operators, in which Schibye et al[21] reported that people 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 incidence 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[13] 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.[1] 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.

Regarding back pain prevalence, the results of this study are similar to results found in previous studies. In the current results, for example, 20% of the unexposed group and 35% of the exposed group reported having back pain lasting a week or more in the past 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 past 12 months.[3,10] When asked about the cause of LBP, 6.3% of respondents in the 1988 survey reported that the LBP was caused by repetitive activities at work. In the current study, 4% of the unexposed group and 30.4% of the exposed group attributed LBP to repetitive activities at work. Moreover, in the 1988 survey, 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 domestic workers.[3,10] Finally, lifetime prevalence rates for LBP (47%) in the current study were similar to lifetime prevalence rates found in previous studies of LBP in the Nordic population (between 60% and 65%).[14] The lower rates in the current study may be caused by differences in the case definition.

In addition to the LI, job satisfaction was the only variable shown to be significantly related to reported LBP. It is not clear, however, whether job dissatisfaction could be a cause of back pain or back pain reporting, or conversely, whether back pain could be a cause of dissatisfaction. Little is known about the correlation between job satisfaction and LBP. One study reported that musculoskeletal symptoms may cause people to seek another job.[21] It is likely that these workers could also have been dissatisfied with their jobs. The only longitudinal study of LBP we could find in which job dissatisfaction was evaluated as a predictor of back pain showed no correlation.[4] Bigos et al,[5] in a study that is sometimes cited to show a correlation between psychosocial factors and back disorders, actually studied the correlation between psychosocial factors and workers actively reporting acute back injury to the plant management, filing a back-related incident report, or filing an industrial insurance claim, not prevalence of back pain symptoms. In a cross-sectional study such as the current one, a model excluding job dissatisfaction is more appropriate, because job dissatisfaction is likely to be caused by the outcome, LBP. With job dissatisfaction in the model, the

OR for LBP in the $2<\text{LI}\leq 3$ category is still statistically significant.

The correlation between individual multipliers in the RWL equation and prevalence of LBP was investigated to see whether any intermediate variables would be good predictors of LBP. Unfortunately, there was insufficient power to evaluate the predictive power of individual multipliers. Future studies are planned in which additional data on individual multipliers will be collected.

Further examination of the RWL and LIs (Table 2) raises some interesting issues. First, although data are limited in some categories and there is wide variability in the magnitude of the RWL values and weights lifted within each LI category, it appears that the average RWL values in the four exposed LI categories are similar in magnitude (16.0, 14.9, 14.4, and 12.2 lb). It could be interpreted from this finding that the LI equation is more sensitive to the magnitude of the weight lifted than to the differences in job characteristics. Because the magnitude of variability for the RWL and weights within each LI category is large, however, this interpretation does not appear to be accurate. Another interpretation could be that job designers either explicitly or implicitly design jobs to fit most workers, resulting in a narrow range of RWL values for typical lifting jobs. In a recent study using a simulation model of manual lifting and the RWL, for example, it was concluded that for 95% of all possible combinations of lifting task variables, the RWL values were (on average) equal to or smaller than 20 lb.[12] The implications of this potential finding is that if weights of objects were limited to 25 lb, then most lifting jobs would have LIs below 1.5. More research is needed to determine whether a single weight limit would protect most workers.

A second issue of interest is that there were no consistent trends between LI categories for any of the multipliers. Although the horizontal multiplier and frequency multiplier typically had the greatest effect on the RWL within each category, no single multiplier consistently decreased as the LI category increased. This finding indicates that, even though some of the factors are more important than others in predicting risk of LBP, all of the factors should be considered when determining the RWL.

Study Limitations

As with all epidemiologic studies, there were several limitations to this study. To minimize the effects of these limitations, an attempt was made to choose the solution that would bias the study results toward the null. First, 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 the 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, the unexposed population included many office workers who may have worked most of the day in a seated posture. Because investigators have shown a correlation between LBP and sustained use of the seated posture, their rates of LBP may be higher than those in a truly unexposed population. This would also result in a bias of the results toward the null. Third, within those workplaces evaluated for this investigation, there were few lifting jobs that had LIs below 2.0, and especially below 1.0. This resulted in extremely small study populations in the low-exposure categories, thus severely limiting ability to estimate risk accurately at those exposure levels.

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, the variability was managed in a variety of ways. When appropriate, the NIOSH multitask method was used to account for known variability. In some cases, however, the multitask method could not be used because of difficulty in determining the distribution of the variability. For those jobs, the worst-case characteristics were chosen to compute the LIs. More detailed methods of accounting for variability may be needed to refine risk assessment capability. Nonetheless, in this case, the decision to choose the worst case would bias the results toward the null.

The companies who agreed to participate in this study had been proactive in applying ergonomics before the current 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 LIs below 3.0. Also, there is a possibility that the jobs evaluated would not be representative of jobs that may have been found in other workplaces, which may result in a differential bias of risk in either direction.

Finally, comparing the results of this study with those in others in which the the work-relatedness of LBP has been investigated presents some difficulties. Investigators of low back disorders have used a variety of health outcome measures: among them, self-reported LBP, Occupational Safety and Health Administration 200 Logs (of injuries and illnesses reported), workers' compensation records, days lost, and restricted duty. 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 people who move into restricted duty or change jobs because of low back problems. Similarly, there are differences among workers' compensation claims from state to state. For this reason, it is difficult to compare results of many of the epidemiologic studies that have been undertaken in the past.[8]

Conclusions and Recommendation for Future Research

First, even though LBP is a common disorder, analysis of the results indicates that the LI may be a useful indicator of risk of LBP caused by manual lifting. Specifically, the current findings indicate that a worker who continuously performs a manual lifting job with an LI greater than 2.0 is at a significantly greater risk of having LBP lasting a week or more during any 12-month period than is a worker in a nonlifting job. Nevertheless, we plan to continue a study similar to this one to gather additional data, because there are not yet sufficient data to determine the precise level of risk associated with jobs with LIs less than 2.0 or greater than 3.0. It appears that selection and survivor effects may hinder ability to evaluate completely the risk of LBP at certain levels of exposure.

Second, although additional data are needed, the current findings indicate that personal and psychosocial factors did not have a significant effect on reports of LBP. Because of the uncertainty of the temporal correlation between reported job dissatisfaction and LBP, however, it was 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 represents a first step in evaluating the LI as a predictor of risk of lifting-related LBP. As such, more data are needed for rigorous examination of the correlation between the LI and risk of LBP. Also, more research is needed to investigate the possible effects of psychosocial and personal factors on the reports of LBP that have been shown in other studies. Finally, research is needed to refine and extend the application of the NIOSH lifting equations 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. We plan to continue a study similar to this study to collect additional data to address these research needs.

Acknowledgments

The authors thank the following for their assistance: Patricia Bertsche, Robert Dick, Glenn Doyle, Cheryl Fairfield, Kathy Grant, Dan Habes, Steve Hudoc, Dahee Kang, Kristina Kemmlert, Leslie McDonald, James McGlothlin, Virginia O'Neill, Wayne Sanderson, Mitch Singal, Steve Smith, Marjorie Wallace, and Ken Wallingford.

References

1. Andersson, G. The epidemiology of spinal disorders. In Frymoyer J, ed. The Adult Spine: Principles and Practice. New York: Raven Press 1991:107–46.
2. Axelson O, Fredriksson M, Ekberg K. Use of the prevalence ratio vs the prevalence odds ratio as a measure of risk in cross sectional studies. Occup Environ Med 1994;51:574.
3. Behrens V, Seligman P, Cameron L, Methias T, Fine L. The prevalence of back pain, hand discomfort, and dermatitis in the US working population. Am J Pub Health 1994;84:1780–5.
4. Biering-Sorenson F, Thomsen C, and Hilden J. Risk indicators for low-back trouble. Scand J Rehabil Med 1989; 21:151–7.
5. Bigos, S, Battie M, Spengler D, et al. A prospective study of work perceptions and psychosocial factors affecting the report of back injury. Spine 1991;16:1–6.
6. Borg G. Psychological scaling with applications in physical work and perception of exertion. Scand J Work Environ Health 1990;16(Suppl 1):55–8.
7. Corlett E, Bishop R. A technique for assessing postural discomfort. Ergonomics 1976;19:175–82.
8. Frank JW, Pulcins MA, Kerr MS, Shannon HS, and Stansfeld SA. Occupational back pain: An unhelpful polemic. Scand J Work Environ Health 1995;21: 3–14.
9. Garg A, Saxena U. Effects of lifting frequency and technique on physical fatigue with special references to psychophysical methodology and metabolic rate. J Am Ind Hygiene Assoc 1979;46:53–9.
10. Guo H, Tanaka S, Cameron L, et al. Back pain among workers in the United States: National estimates and workers at high risk. Am J Ind Med 1995;28:591–602.
11. Hurrell J, McLaney M. Exposure to job stress: A new psychometric instrument. Scand J Work Environ Health 1988;14(Suppl 1):27–8.
12. Karwowski W, Gaddie P. Design limits for manual lifting tasks based on computer simulation of 100,000 jobs using the revised NIOSH lifting equation. Technical Report, Center for Industrial Ergonomics, Louisville, KY: University of Louisville, 1995.
13. Lavender S, and Marras W. The use of turnover rate as a passive surveillance indicator for potential low back disorders. Ergonomics 1994;37:971–78.
14. Leboeuf-Yde C, Lauritsen M. The prevalence of low back pain in the literature. Spine 1995;20:2112–8.
15. Lee J, Chia KS. Estimation of prevalence rate ratios for cross sectional data: An example in occupational epidemiology. Br J Ind Med 1993;50:861–4.
16. Liles DH, Mahajan P, Ayoub MM. An evaluation of two methods for the injury risk assessment of lifting jobs. Proceedings of the Human Factors Society 27th Annual Meeting. Santa Monica, CA: Human Factors Society, 1993:279–83.
17. Marras W, Lavender S, Leurgans S, et al. The role of three-dimensional trunk motion in occupationally-related low back disorders. Spine 1993;18:617–28.
18. Marras W, Lavender S, Leurgans S, Fathallah F, Ferguson S, Rajulu S. Biomechanical risk factors for occupationally related low back disorders. Ergonomics 1995;38:377–410.
19. National Institute for Occupational Safety and Health. The national occupational exposure survey. Cincinnati, OH: DHHS(NIOSH) Publication no. 89-103, 1989.
20. SAS Institute Inc., SAS Circle, Box 8000, Cary NC.
21. Schibye B, Skov T, Ekner D, Christiansen J, Sjogaard G. Musculoskeletal symptoms among sewing machine operators. Scand J Work Environ Health 1995;21:427–34.
22. Waters T, Putz-Anderson V, Garg A, Fine L. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics 1993;36:749–76.
23. Waters T, Putz-Anderson V, Garg A. Applications manual for the revised NIOSH lifting equation. Cincinnati, OH: DHHS(NIOSH) Publication no. 94-110, 1994.
24. Waters TR, Baron SL, Kemmlert K. Accuracy of measurements for the revised NIOSH lifting equation. Applied Ergonomics 1998;29:433–8.
25. Webster B and Snook S. The cost of 1989 workers' compensation low back claims. Spine 1994;19:1111-6.

Address reprint requests to

Thomas R. Waters, PhD
NIOSH (C24)
4676 Columbia Parkway
Cincinnati, OH 45226

■ Appendix A

NIOSH Lifting Equation
A. Calculation for Recommended Weight Limit
RWL = LC * HM * VM * DM * AM * FM * CM (* indicates multiplication)

Recommended Weight Limit

Component	Metric	U.S. Customary
LC = load constant	23 kg	51 lbs
HM = horizontal multiplier	(25/H)	(10/H)
VM = vertical multiplier	$(1-(0.003\lvert V-75\rvert))$	$(1-(0.0075\lvert V-30\rvert))$
DM = distance multiplier	(0.82 + (4.5/D))	(0.82 + (1.8/D))
AM = asymmetric multiplier	(1-(0.0032A))	(1-0.0032A))
FM = frequency multiplier	(from Table A1)	
CM = coupling multiplier	(from Table A2)	

Where:
H = horizontal location of hands from midpoint between the ankles; measure at the origin and the destination of the lift (cm or in)
V = vertical location of the hands from the floor; measure at the origin and destination of the lift (cm or in)
D = vertical travel distance between the origin and the destination of the lift (cm or in)
A = angle of asymmetry–angular displacement of the load from the sagittal plane; measure at the origin and destination of the lift (degrees)
F = average frequency rate of lifting measured in lifts/min
Duration is defined to be: ≤1 hour; ≤2 hours; or ≤8 hours assuming appropriate recovery allowances

Appendix A1. Frequency Multiplier (FM): NIOSH Lifting Equation*

	Work Duration					
	≤1 h		≤2 h		≤8 h	
Frequency Lifts/min	V <75	V ≥75	V <75	V ≥75	V <75	V ≥75
0.2	1.00	1.00	0.95	0.95	0.85	0.85
0.5	0.97	0.97	0.92	0.92	0.81	0.81
1	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.72	0.45	0.45
5	0.80	0.80	0.60	0.60	0.35	0.35
6	0.75	0.75	0.50	0.50	0.27	0.27
7	0.70	0.70	0.42	0.42	0.22	0.22
8	0.60	0.60	0.35	0.35	0.18	0.18
9	0.52	0.52	0.30	0.30	0.00	0.15
10	0.45	0.45	0.26	0.26	0.00	0.13
11	0.41	0.41	0.00	0.23	0.00	0.00
12	0.37	0.37	0.00	0.21	0.00	0.00
13	0.00	0.34	0.00	0.00	0.00	0.00
14	0.00	0.31	0.00	0.00	0.00	0.00
15	0.00	0.28	0.00	0.00	0.00	0.00
>15	0.00	0.00	0.00	0.00	0.00	0.00

* Values of V are in cm; 75 cm = 30 in.

Appendix A2. Coupling Multiplier: NIOSH Lifting Equation

	Coupling Multipliers	
Couplings	V <75 cm (30 in)	V ≥75 cm (30 in)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90