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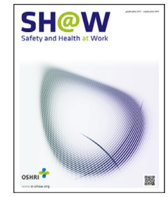

Original Article

Non-chemical Risk Assessment for Lifting and Low Back Pain Based on Bayesian Threshold Models

Q9 Sudha P. Pandalai [1,*], Matthew W. Wheeler [1], Ming-Lun Lu [2]

[1] *Education and Information Division, Risk Evaluation Branch, National Institute for Occupational Safety and Health, Cincinnati, OH, USA*
[2] *Division of Applied Research and Technology, Organizational and Human Factors Branch, National Institute for Occupational Safety and Health, Cincinnati, OH, USA*

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A B S T R A C T

Background: Self-reported low back pain (LBP) has been evaluated in relation to material handling lifting tasks, but little research has focused on relating quantifiable stressors to LBP at the individual level. The National Institute for Occupational Safety and Health (NIOSH) Composite Lifting Index (CLI) has been used to quantify stressors for lifting tasks. A chemical exposure can be readily used as an exposure metric or stressor for chemical risk assessment (RA). Defining and quantifying lifting nonchemical stressors and related adverse responses is more difficult. Stressor–response models appropriate for CLI and LBP associations do not easily fit in common chemical RA modeling techniques (e.g., Benchmark Dose methods), so different approaches were tried.

Methods: This work used prospective data from 138 manufacturing workers to consider the linkage of the occupational stressor of material lifting to LBP. The final model used a Bayesian random threshold approach to estimate the probability of an increase in LBP as a threshold step function.

Results: Using maximal and mean CLI values, a significant increase in the probability of LBP for values above 1.5 was found.

Conclusion: A risk of LBP associated with CLI values > 1.5 existed in this worker population. The relevance for other populations requires further study.

1. Introduction

Musculoskeletal disorders (MSDs) are common occupational disorders [1–3], comprising 33% of occupational injuries involving lost workdays [4]. Recent work-related MSD treatment, decreased wages, and other indirect cost estimates total $45–54 billion annually [5]. Elevated lifetime workplace MSD prevalence rates, particularly low back pain (LBP), occur across occupations, including farmers (75%) [6] and manual material handlers (63.5%) [7]. Little research has been conducted to investigate a link between quantifiable stressors and LBP at the individual level [8–10]. The objective of the study was to fill this research void.

Meta-analysis of eight studies of occupational lifting-related LBP estimated annual incidence for lifting > 25 kg/lift and >25 lifts/d of 4.32% and 3.50%, versus those without lifting tasks [11]. Meta-analysis of 220 peer-reviewed studies, from 1966 to 2005, of variable study design, size, exposure, and LBP assessment, calculated odds ratios (ORs) for report of LBP, versus unexposed workers, of 1.1–2.0 (posture-related exposures), and 1.4–2.1 (job-task-related increased lower back force) [12]. Such analyses utilized aggregate data, not individual-level measures of an exposure (or stressor) and health outcome, to examine potential limits for physical exposures.

The National Institute for Occupational Safety and Health (NIOSH) Lifting Equation calculates the Lifting Index (LI) using musculoskeletal position and biomechanical measurements of front-facing, two-handed lifts of compact loads, close to the body, without twisting, stooping, or reaching up or forward [13–15]. Job tasks are measured at the work site, or from video recordings with measurements estimated in the laboratory by mimicking tasks using a motion capture system [16]. The recommended weight limit (RWL) is the product of a load constant and multipliers for horizontal, vertical, distance, asymmetry, frequency, and coupling parameters [13]. The asymmetry multiplier represents the carried load angle relative to the midsagittal plane, using “neutral body posture, rather

* Corresponding author. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Education and Information Division, MS C-15, 1090 Tusculum Avenue, Cincinnati, OH 45226, USA.
E-mail address: SPandalai@cdc.gov (S.P. Pandalai).

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than…position of the feet or the extent of body twist” [17]. Weight of load divided by RWL equals the LI. The LI is a unit-less value that “provides a relative estimate of the level of physical stress associated with a particular manual lifting task” [13], with increasing LI reflecting increasing levels of stress. The Composite Lifting Index (CLI) extends the LI for multitask lifts [9,18]. Analysis of CLI and self-reported LBP ($\geq$ 7 days, even once in the preceding year) found a significant relationship between CLI $>$ 2 and LBP, versus individuals with CLI $\leq$ 1 {mean CLI: odds ratio (OR) = 5.1 [95% confidence interval (CI) = 1.1–24.5]; maximum CLI: OR = 6.5 (95% CI = 1.4–29.7)} [9]. The CLI and LBP association presents an opportunity to explore risk assessment (RA) methods to evaluate a nonchemical (i.e., physical) exposure and relevant MSD health effect.

Relatively, quantitative RA has been well developed for evaluating chemical exposure and health outcome relationships [19], but RA methods have not been as well established for nonchemical hazards. The goal of chemical RA methods is to quantify the exposure corresponding to a specified increase in risk, defined as the benchmark dose (BMD). Analyses using the BMD approach, however, may not be optimal for evaluating exposure–response associations relevant to MSD. Traditional exposure–response modeling often assumes that risk is strictly increasing with exposure, typically not allowing for threshold models. This assumption may not apply to physical exposures causing MSD. The present work assumes a model where increasing LBP is related to some unknown threshold of exposure that can be estimated. Here, unlike BMD analyses, the probability of LBP is constant before and after the threshold, allowing the threshold estimate, and corresponding lower bound, to serve as estimates of increased risk. This method development paper evaluates a measure of exposure to a lifting activity and an MSD related health outcome, with an illustration of characterizing risks of LBP using CLI data.

2. Materials and methods

This analysis included 138 workers lacking LBP for 3 months, and minimally 6 months, pre-study baseline. The original analysis used data from 78 workers who had been employed in the same job and without LBP 1 year preceding study baseline [9]. The question, “In the past 12 months, have you had LBP every day for a week (7 days) or more (even 1 occurrence),” assessed baseline and 1-year LBP. CLI (baseline mean and maximum), and other lifting characteristics, were calculated using baseline video tapings of tasks. Workers lifted and assembled dryer parts (3.2–10 kg); jobs included repetition, multiple tasks, task rotation, standing/sitting, nonlifting work, defined work locations, and breaks. Covariates included demographics, nonwork physical activities, and job factors. Categorization of continuous variables in the present analysis used BLS [4] categories for age; National Heart, Lung, and Blood Institute [20] definitions for BMI; and quartile values for “years working with company” groupings.

Basic analysis of LBP-covariate and LBP-CLI associations used SAS version 9.3 (SAS Institute, Cary, NC, USA). A variation of Probit regression was used to model the probability of LBP given exposure to lifting as defined by the mean and maximum CLI. Standard methods such as logistic and Probit regression were unable to describe the given data adequately because they assumed a linear relationship with the CLI, and the probability of LBP did not increase much after CLI values of 2.5 in these data. Furthermore, approaches that categorized the CLI with cut points may not have been appropriate, as the number and location of the cut points were arbitrary. For flexibility in the model form, the response was not assumed to be strictly linear; instead we assumed that the response was a step function where the probability of adverse response increased after some unknown threshold of exposure. This allowed specification of the critical exposure level using the threshold while making minimal assumptions on the shape of the exposure–response relationship. The model assumed three unknown parameters of the threshold, the background probability of response, and the magnitude of increased probability of response after the threshold, which was estimated using Bayesian methods (see Appendix I). All modeling of the probability of LBP utilized MATLAB version 2013b (The MathWorks, Natick, MA, USA). Q2

3. Results

3.1. Descriptive statistics and univariable analyses of data

Decreased LBP was associated with engaging in, on average, 10–19 h/wk of nonwork-related activities with bending/twisting, compared to the reference group that engaged in $<$ 5 h/wk of these types of nonwork activities (OR = 0.29; 95% CI = 0.1, 0.84; $p = 0.02$). Decreased LBP was associated with working 10–19 weeks of overtime in the past year compared to working 1–9 weeks of overtime in the past year (OR = 0.028; 95% CI = 0.1, 0.79; $p = 0.016$). Decreased LBP was associated with a length of overall employment of 5–10 years compared to the reference group with $<$ 2 years of overall employment. Other LBP-covariate associations were nonsignificant (Tables 1 and 2). LBP correlated to lifts per shift and Q3

Table 1
Results of univariable analysis for the expanded sample from the NIOSH study of the Composite Lifting Index and Self-reported LBP at 1-year follow-up—demographic variables

Variables	n	% LBP	Mean	SD	OR*	95% CI
Sex	137	–	–	–	–	–
Male	105	17.1	–	–	Ref	–
Female	32	9.4	–	–	0.5	0.14–1.82
Age (y)	138	–	38.2	11.2		–
18 to < 25 (none < 18)	21	9.5	–	–	Ref	–
25 to < 34	34	17.7	–	–	0.49	0.09–2.7
35 to < 44	40	12.5	–	–	0.74	0.13–4.17
45 to < 54	32	18.75	–	–	0.46	0.08–2.51
55 to < 64 (none > 64)	11	18.18	–	–	0.47	0.06–3.92
Race	138	–	–	–	–	–
Caucasian	136	15.4	–	–	–	–
Other	2	–	–	–	–	–
Education	138	–	–	–	–	–
College graduate, some college	31	16.1	–	–	Ref	–
High School, some high school	107	14.95	–	–	1.09	0.37–3.27
Length of employment (y)	138	–	4.7	5.8	–	–
< 2 (minimum 0.17)	52	13.04	–	–	Ref	
From 2 to < 5	47	18.42	–	–	0.61	0.18–2.07
From 5 to < 10	20	18.75	–	–	0.25	0.07–0.94†
≥ 10 (maximum 32)	19	13.33	–	–	0.57	0.12–2.65
Body mass index (kg/m^2)	137	–	28	6.7	0.97	0.9–1.05
From 18.3 to < 25 (min 18.3)	48	16.7	–	–	Ref	–
From 25 to < 30	48	18.8	–	–	0.85	0.3–2.41
From 30 to < 35	21	4.8	–	–	3.9	0.46–33.38
From 35 to < 40	11	27.3	–	–	1.11	0.26–4.68
≥ 40 (max 48.8)	9	0	–			
Smoking status	137	–	–	–	–	–
Non-smoker	45	13.3	–	–	Ref	–
Smoker	45	15.6	–	–	0.81	0.25–2.64
Past-smoker	47	17.0	–	–	0.73	0.23–2.30
Alcohol consumption in the past year (drinks/wk unless otherwise noted)	137	–	–	–	–	–
None	34	14.7	–	–	Ref	–
≤ 12/y	30	16.7	–	–	0.83	0.22–3.21
< 3	35	11.4	–	–	1.29	0.32–5.28
3–7	27	11.1	–	–	1.33	0.29–6.15
8–14	3	66.7	–	–	0.08	0.01–1.1
> 14	8	25.0	–	–	0.5	0.08–3.21

* OR calculated using logistic regression methods.
† Statistically significant at $p < 0.05$.
CI, confidence interval; DL, decision latitude; LBP, low back pain; M, mean; Max, maximum; Min, minimum; NIOSH, National Institute of Occupational Safety and Health; OR, odds ratio; PD, psychological demand; SD, standard deviation.