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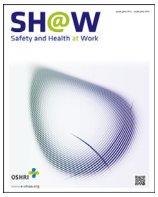

Original Article

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

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ABSTRACT

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

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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 ≤ 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).

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

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†
$\geq$ 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
$\geq$ 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	–
$\leq$ 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.

Table 2

Results of univariable analysis for the expanded sample from the NIOSH study of Composite Lifting Index and self-reported LBP at 1-year follow-up—work schedule and organization variables

Variables	n	% LBP	Mean	SD	OR*	CI
Self-rated health	134	–	–	–	–	–
Excellent	17	0	–	–	2.02	0.72–5.69
Very good	45	13.3	–	–		
Good	62	17.7	–	–	Ref	–
Fair	9	22.2	–	–		
Poor	1	0	–	–		
2nd job (yes vs. no; $n = 137$)	13	7.6	–		0.43	0.05–3.52
NW bent/twisted back posture (h/wk in past y)	138	–	–	–	–	–
< 5	72	9.7	–	–	Ref	–
5–9	37	27.0	–	–	0.29	0.10–0.84†
10–19	14	7.1	–	–	1.40	0.16–12.36
≥ 20	15	20.0	–	–	0.43	0.1–1.9
NW MMH (h/wk in past y)	137	–	–	–	–	–
< 5	75	16.0	–	–	Ref	–
5–9	38	15.8	–	–	1.00	0.34–2.91
10–19	10	10.0	–	–	1.69	0.2–14.47
≥ 20	14	14.3	–	–	1.13	0.22–5.68
Sports or hobbies (yes vs. no; $n = 138$)	62	14.5	–	–	0.91	0.36–2.3
Job tenure with company (y)	137		–	–	–	–
From 1 to < 3	44	13.5	–	–	Ref	–
From 3 to < 5	13	0.0	–	–	Ref	Ref
From 5 to < 10	35	20.0	–	–	0.46	0.14–1.51
≥ 10	45	17.8	–	–	0.53	0.17–1.67
Work shift	138		–	–	–	–
1st	60	16.7	–	–	Ref	–
2nd	44	11.4	–	–	1.56	0.49–4.93
3rd	34	17.7	–	–	0.93	0.31–2.84
Work time/d (h)	129			–		
≤ 8	110	14.6	–	–	Ref	–
> 8	19	10.5	–	–	0.69	0.14–3.28
Work d/wk	129		–	–	–	–
≤ 5	126	13.5	–	–	Ref	–
> 5	3	33.3	–	–	3.21	0.28–37.31
Overtime in past y (wk)	127	–	–	–	–	–
1–9	93	11.8	–	–	Ref	–
10–19	27	29.6	–	–	0.28	0.10–0.79†
≥ 20	7	28.6	–	–	0.3	0.05–1.71
Hands & arms activity (0–10, rapidest)	138	15.2	7.2	1.4	1.08	0.77–1.50
Overall physical efforts (0–10, maximal)	137	15.3	5.6	1.9	1.09	0.86–1.39
Job strain (4 domains)	137	–	–	–	–	–
High DL + Low PD	40	12.5	–	–	Ref	–
Low DL + Low PD	34	17.7	–	–	0.65	0.18–2.34
High DL + high PD	33	12.1	–	–	1.01	0.25–4.10
Low DL + high PD	30	20.0	–	–	0.56	0.15–2.03
Low supervisor social support ($n = 137$)	49	8.16	–	–	0.40	0.3–1.27
Low coworker social support ($n = 137$)	52	13.5	–	–	0.79	0.3–2.10
Low job security ($n = 138$)	98	13.3	–	–	0.61	0.23–1.61
Low job satisfaction ($n = 138$)	121	15.7	–	–	1.4	0.3–6.61

* OR calculated using logistic regression methods.

† Statistically significant at $p < 0.05$.

CI, confidence interval; DL, decision latitude; LBP, low back pain; M, mean; MMH, manual material handling; NIOSH, National Institute of Occupational Safety and Health; NW, non-work; OR, odds ratio; PD, psychological demands; SD, standard deviation.

maximum lifting frequency [0.18 ($p = 0.04$) and 0.19 ($p = 0.03$), Table 3]. Omitting three individuals with accident-related LBP did not change results.

3.2. *Modeling the probability of low back pain*

It is unknown if any level of exposure corresponds to an increase in LBP. Our model allowed for the possibility that the magnitude of the adverse response was exactly zero. This corresponds to the hypothesis that there is no increase in LBP for any level of the exposure. This hypothesis was tested, as described in Appendix I, using Bayes factors [21]. A Bayes factor, unlike a traditional hypothesis test, gives a subjective measure that the hypothesis is supported given these data, in terms of posterior odds of the two hypotheses. Although the method is subjective, the procedure can be calibrated to have the same type-I error as frequentist tests [22]. In our example, we rejected the hypothesis that there was no effect if the Bayes factor was ≥ 2.5, which corresponded to $p = 0.05$. To adjust for the covariates described above, all covariates except the exposure variable were modeled using the Bayesian Lasso [23]. This method was a Bayesian method of variable selection where unimportant variables were estimated to be close to zero while variables that were important were nonzero. This method accounted for covariates while not explicitly removing them from the analysis and reanalyzing these data with the reduced model.

3.3. *Modeling lifting index and self-reported LBP data*

For both mean and maximum CLI values, the threshold effect was estimated to be 1.8, with the lower 95% credible limit of 1.2. Fig. 1 gives the posterior distribution of the threshold value and shows the range of threshold values supported by these data. Corresponding to this threshold is the increased probability of LBP after this value. Here, the probability of increased LBP was estimated to be ~8% greater after the threshold. Fig. 2 shows the central estimate and corresponding 95% point wise credible intervals of LBP. Here, this increase was related to the location of the threshold. For lower threshold values, the increase was estimated to be less, which may indicate a gradual increase in the probability of LBP with increased CLI values; however, due to the limited sample size, the threshold became estimable at CLI values of ~1.5. Bayes factors were calculated to be 5.1 for the maximum CLI and 3.7 for the mean CLI; both exceeded the 2.5 threshold for significance. This suggests that these data supported the hypothesis that there was an increased probability of LBP for greater CLI values, and this increased probability was ~8%.

3.4. *Characterizing risk—one possible approach and an example*

In an example of characterizing risk, using this methodology, the location of the threshold can potentially correspond to a maximum safe exposure level, and exposures below this level may not be associated with increased levels of LBP. Furthermore, the estimation of the magnitude of the increase past this threshold may give an indication of the severity of the increase. These two values could possibly give risk managers information on the variability of risk with exposure. For risk management purposes, one approach is to assume a 100 $(1 - \alpha)$% lower limit, using the convention based on the α level. This assumption may or may not have actual workplace relevance for CLI and self-reported LBP values such as those in this study, but is illustrative. Here, the terms threshold exposure level (THEL) and the lower corresponding 100 $(1 - \alpha)$% lower limit (THELL) were proposed. For the above model, the estimated threshold effect was 1.8, which would be the THEL, with a corresponding lower limit, or THELL, of 1.2, where $\alpha = 0.05$%. This example calculation suggests that, in these data, CLI < 1.2 was associated with lower risk of self-reported LBP. This value was slightly larger than 1, which is the value previously defined as safe for lifting tasks relevant to the LI [13,17].

4. Discussion

The CLI exposure metric assesses front-facing, two-handed lifting of compact loads close to the body, without twisting, stooping, or reaching up or forward. This analysis linked CLI to self-reported LBP in manufacturing workers. Modeling this response from a

Table 3

Descriptive statistics of lifting variables at baseline and their association with the presence of self-reported LBP at 1-year follow-up

Variable	All individuals ($n = 138$)		Non-LBP ($n = 117$)		LBP ($n = 21$)		SCC	p
	M	SD	M	SD	M	SD		
No. of lifts/shift	119.6	144.5	108.7	137.7	180.1	169.1	0.18	0.04*
Lift time/shift (min)	222.3	267.4	203.5	251.9	327.3	328.7	0.16	0.07
Mean lifting frequency/min	7.3	3.4	7.1	3.2	8.9	4.2	0.16	0.07
Mean load (kg)	12.9	5.2	13.1	5.3	11.8	5.2	0.06	0.49
Mean CLI	1.5	0.97	1.9	0.9	2.1	0.9	0.11	0.19
Maximum lifting frequency/min	8.6	4.3	8.2	4.1	10.6	4.9	0.19	0.03*
Maximum load (kg)	18.7	12.8	18.7	13.1	18.6	10.98	0.02	0.83
Maximum CLI	1.97	1.5	2.2	1.1	2.8	1.3	0.14	0.09

* Statistically significant at $p < 0.05$.

CLI, Composite Lifting Index; LBP, low back pain; M, mean; SCC, Spearman rank correlation coefficient; SD, standard deviation.

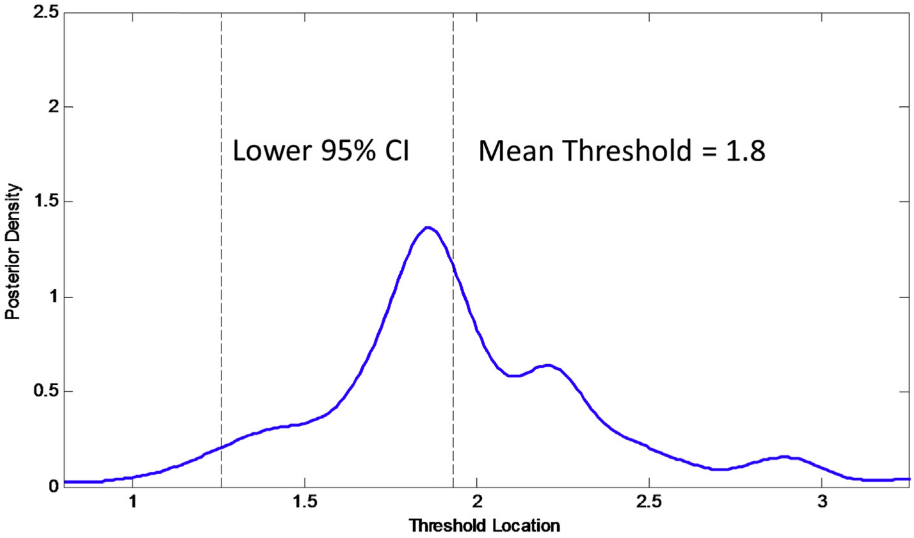

Fig. 1. Posterior distribution of the threshold location, given there is a threshold. The y-axis is the posterior density; threshold location is on the x-axis. The mean threshold value is estimated to be 1.8 with 95% lower credible interval (CI) of 1.28.

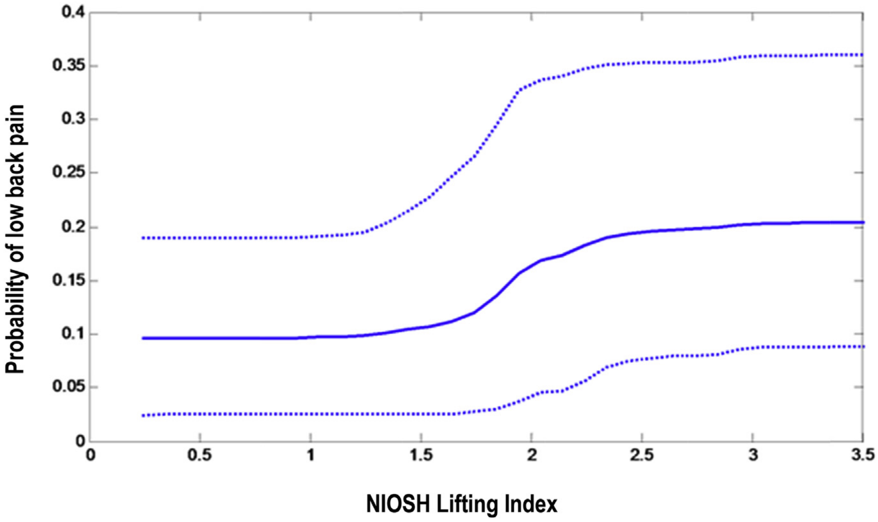

Fig. 2. Estimated probability of low back pain for different values of the Composite Lifting Index. The central estimate (solid line) and the 95% pointwise credible intervals (dotted lines) are presented. NIOSH, National Institute for Occupational Safety and Health.

Bayesian perspective, with Bayesian Hypothesis testing of the significance of a threshold of CLI for the occurrence of LBP, revealed a significant increase in the response at exposures > 1.8; up to a 10% increase in the probability of LBP after this threshold; and similar exposure–response relationships depending on the CLI threshold used (i.e., maximum or mean CLI). Basic analysis showed decreased LBP associated with 10–19 h/wk of nonwork physical activities including bending/back twisting, 10–19 weeks of overtime in the past year, 5–10 years of employment, and increased LBP correlated with lifts per shift and maximum lifting frequency. Implications of these findings for causality or other occupational groups are unclear.

We presented one possible approach to characterize the risk of LBP using the threshold exposure level lower bound. This was done using a 100 $(1 - \alpha)$% lower bound where $\alpha = 0.05$. Based on this analysis, the variable of LBP is likely best assessed using nonparametric Bayesian approaches, but this warrants further evaluation and validation. Here, LBP was defined as at least one occurrence of pain for ≥ 7 days in the past year. In the Backworks prospective cohort study [8], a case was "defined as regional LBP in the lumbosacral area, of any pain intensity, lasting at least 1 day" and peak LI values > 3.0, versus < 1.0, were associated with increased LBP (OR: 2.6, 95% CI: 1.22–5.31), but not values of 1.0–3.0. Defining and operationalizing LBP as a measure of a MSD adverse health effect is complex and evolving [7].

Strengths of this methods development effort include the use of prospective data and of the NIOSH lifting equation, a previously developed tool, to assess exposure. Limitations include the lengthy time period between exposure and outcome assessment (1 year), resulting in outcome assessment being vulnerable to recall bias. To use LBP as an outcome in RA to drive the development of risk management strategies, the definition of background rates is important to guide the determination of the extra risk of LBP due to occupational exposures. Extra risk means the amount of extra outcome that would occur among individuals, beyond the baseline level of their risk for that outcome, given their exposure to the hazard of interest [24]. In RA, the goal is to characterize extra risk for an outcome, given a specific exposure. How this concept is to be defined and applied in characterizing the risk of LBP, as a consequence of lifting, requires additional data that allows a more nuanced definition of an adverse effect and derivation of background rates.

The CLI as an exposure metric for nonchemical RA of MSD is relevant for lifts with defined characteristics [13,17]. Work to understand the generalizability [9,14,18,25–27] of the CLI, and its utility as an exposure metric [28–30], is ongoing. The applicability of the Bayesian RA method presented here for characterizing risks of MSD remains to be determined. Further research would help validate and refine this approach regarding the association of the revised NIOSH lifting equation CLI and self-reported LBP, and the broader utility of this method in other exposure-response contexts related to MSD.

Conflicts of interest

The authors declare that they have no conflicts of interest. The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of NIOSH. Mention of any company or product does not constitute endorsement by NIOSH.

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Appendix I. Development of the Bayesian Threshold Model.

Assume that the probability of LBP $pr(Y_i = 1|d)$ can be modeled using Probit regression (Eq. 1) as:

$$pr(Y_i = 1|d) = \boldsymbol{\Phi}(\boldsymbol{\alpha} + \boldsymbol{\beta}\mathrm{I}(\mathrm{d} > \tau)) \tag{1}$$

Here $\boldsymbol{\alpha}$ corresponds to the background probability of response, $\boldsymbol{\beta}$ is the increased probability of response after the threshold τ, and $\boldsymbol{\Phi}$ corresponds to the cumulative distribution function of a standard normal distribution. All parameters are assumed unknown with the following priors (Eqs. 2–4):

$$\boldsymbol{\alpha} \sim \mathrm{N}(0, 1) \tag{2}$$

$$\boldsymbol{\beta} \sim \boldsymbol{\pi}\ 1(\boldsymbol{\beta} = 0) + (1 - \pi)\mathrm{TN}(0, 1, 0, \infty)\ 1(\boldsymbol{\beta} > 0) \tag{3}$$

$$\boldsymbol{\tau} \sim UNIFORM(0, max(d)). \tag{4}$$

The quantity N(0,1) represents a normal random variable with mean 0, variance 1. $\mathrm{TN}(0, 1, 0, \infty)$ is the truncated normal distribution having mean 0, variance 1, which is left truncated at 0 and right truncated at infinity. The prior $\boldsymbol{\beta}$ over allows for the coefficient to be exactly zero by placing positive probability at zero. Additionally, the coefficient is given a truncated normal distribution with mean 0, variance 1, for all values greater than zero. This prior restricts $\boldsymbol{\beta}$ to be positive or exactly zero, corresponding to the belief the effect is positive. Finally, the threshold value $\boldsymbol{\tau} \sim UNIFORM(0, max(d))$ corresponds to a uniform random variable defined over the range of observed values. This places an uninformative prior over the threshold value stating the threshold can exist anywhere within the range of the observed data. Posterior distribution estimation used Monte Carlo Markov chain methods; 100,000 posterior samples were taken with the first 10,000 disregarded as burn in.

Assuming the threshold response coefficient is either exactly zero or positive allows estimation of the posterior probability of a significant threshold response by monitoring the $\boldsymbol{\beta}$, and estimation of $pr(y|\boldsymbol{\beta} = \mathbf{0})$ and $pr(y|\boldsymbol{\beta} > 0)$ from the posterior sample. The Bayes factor is computed as (Eq. 5):

$$\frac{pr(y|\boldsymbol{\beta} > 0)}{pr(y|\boldsymbol{\beta} = 0)}, \tag{5}$$

to test for the significance of the threshold effect. The hypothesis (Eq. 6):

$$\boldsymbol{H}_0 : \boldsymbol{\beta} = \mathbf{0} \tag{6}$$

versus Eq. 7:

$$\boldsymbol{H}_1 : \boldsymbol{\beta} > 0 \tag{7}$$

is tested to determine the "significance" of the relationship given the observed data. The critical cutoff level of 2.5 corresponds to approximately a type I error of 0.05 in classical testing procedures.

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