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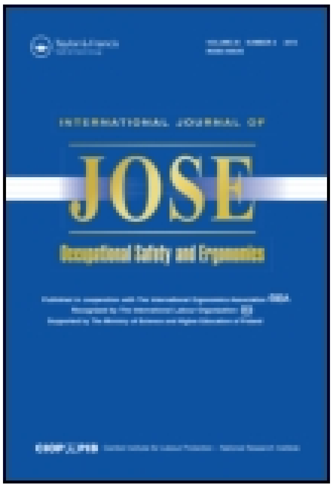

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Evaluation and Quantification of Manual Materials Handling Risk Factors

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This study investigated the ability of the Revised NIOSH Lifting Equation (RNLE) to measure the risk of low back injury as verified by employee health outcomes. In addition, several basic risk factors and combinations of risk factors presumed related to low back disorders were explored. The RNLE was modified to allow analysis of one-handed and two-handed, asymmetric lifts. Predictive performance was not changed. Simplifying the RNLE by removing several variables did not significantly reduce the RNLE's predictive performance. These modifications to the RNLE show promise for increasing both the usability and utility of the RNLE.

Revised NIOSH Lifting Equation low back injury ergonomic modeling

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1. INTRODUCTION AND BACKGROUND

The purpose of this research was to evaluate the Revised NIOSH Lifting Equation (RNLE) and to determine which load characteristics or risk factors or combinations were most predictive of low back disorders. Another goal was to develop a simplified ergonomic model that can more quickly and easily quantify manual materials handling (MMH) risk without substantive loss of predictive ability. Several proposed models were tested using a database of automotive MMH jobs. A simplified tool would allow convenient and cost-effective workplace surveillance of ergonomic risk factors for non-ergonomic professionals.

There is significant evidence that ergonomic risk factors such as posture, force, and repetition, particularly in combination, are causally related to musculoskeletal disorders of the low back (Burdorf & Sorock, 1997; Fathallah, Marras, & Parnianpour, 1998a, b; Herrin, Jaraiede, & Anderson, 1986; Hoogendoorn, Poppel, Bongers, Koes, & Bouter, 1999; Li & Buckle, 1999; National Institute for Occupational Safety and Health [NIOSH], 1997; Neumann et al., 1999; Rosenstock, 1997; Vingard et al., 2000). There are several ergonomic analysis tools currently in use that purport to measure the risk of manual materials handling, specifically the risk of low back injury (Capodaglio, Capodaglio, & Bazzini, 1997; Fathallah et al., 1998a, b; Grieco, Occipinti, Colombini, & Molteni, 1997; Herrin et al., 1986; Hidalgo, Genaidy, & Karwowski, 1997; Karwowski & Brokaw, 1992; Karwowski & Gaddie, 1995; Lavender, Oleske, Nicholson, Andersson, & Hahn, 1999; Marras et al., 1993; Mirka, Kelaher, Nay, & Lawrence, 2000; Mital, Nicholson, & Ayoub, 1997; Neumann et al., 1999; Norman et al., 1998; Potvin, 1997; Shoaf,

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Genaidy, Karwowski, Waters, & Christensen, 1997; Waters et al., 1999; Waters, Putz-Anderson, & Garg, 1994; Zurada, Karwowski, & Marras, 1997). Perhaps no ergonomic model has been used to estimate the risk of MMH jobs more frequently than the Revised NIOSH Lifting Equation (Waters, Putz-Anderson, Garg, & Fine, 1993). This study investigates the ability of the Revised NIOSH Lifting Equation to measure risk as verified by employee health outcomes. The RNLE risk factors were tested using an existing database of MMH jobs with known health outcomes. Several promising models, based on their predictive ability with the automotive database, were developed. These models can be field-tested in work environments with MMH risk factors in subsequent studies.

Low back pain is ubiquitous in modern society. It affects 60 to 90% of all people at some time in their lives and affects on some level up to 42% at any given time (Cassidy, Carroll, & Cote, 1998; Cassidy, & Wedge, 1988; Cote, Cassidy, & Carroll, 1998; Hoogendoorn et al., 1999; Kelsey & Golden, 1987; NIOSH, 1997; Riihimaki, Tola, Videman, & Hanninen, 1989). Over 22 m back pain cases were reported in 1988, with 65% being job-related (Bureau of National Affairs [BNA], 1993; Guo et al., 1995; Guo, Tanaka, Halperin, & Cameron, 1999). Back pain is asserted to be the number one safety challenge to industry and the number one cause of physician visits each year, as well as accounting for 150 to 500 m lost work days (Center to Protect Workers' Rights [CPWR], 1997; Guo et al., 1995, 1999; Kahlil, Abdel-Moty, Rosomoff, & Rosomoff, 1993; NIOSH, 1997; Occupational Safety and Health Administration [OSHA], 1993; Waters et al., 1999)]. Low back pain and injury are a devastating and paramount concern to business and industry, the economy, and the health care system of the USA (Cassidy & Wedge, 1988; Cleary, Thombs, Daniel, & Zimmerli, 1995; CPWR, 1997; Kelsey & Golden, 1987; NIOSH, 1996; OSHA, 1993). Back pain victims who are away from work longer than 6 months have a 50% chance of returning to work, whereas those out for 12 months or more have less than a 10 to 25% chance of returning to their pre-injury work (Cleary et al., 1995; Deyo, 1987; Hagen & Thune, 1998; Kelsey & White, 1980). Back injuries comprise 16 to 37% of all compensable claims totaling more than 1.5 m claims annually (BNA, 1993; Ciriello & Snook, 1999; Cleary et al., 1995; Guo et al., 1995, 1999; Kahlil et al., 1993; NIOSH, 1996, 1997; Waters et al., 1994). Back injuries are the most common and expensive of all work related accidental injuries (NIOSH, 1997). Back surgeries are performed in excess of 250,000 per year and are the third most common surgery in the USA (Cleary et al., 1995). Kahlil et al. (1993) reported that the average surgical case exceeds

U.S. $40,000. Between 7.4 and 15% of the cases consume 90% of the dollars spent on the occupational low back pain phenomena. Total estimated costs to the economy are as much as U.S. $50 to 100 bn each year (BNA, 1993; Guo, et al., 1995; Kahlil et al., 1993). In addition, back injury can also devastate the quality of life of its sufferers and adversely affect their lives in many ways. Despite all of the resources dedicated annually to back injury prevention, it is the most costly injury in the industrial world (Ciriello & Snook, 1999).

In this study, a simplified RNLE equation demonstrated a sensitivity of .76 and specificity .40 for low risk MMH tasks when a lifting index of 1.0 was applied. When a lifting index of 3.0 was used to identify high-risk MMH tasks, sensitivity dropped to .22 and specificity increased to .93 with an odds ratio of 4.0 (1.5–10.3, 95% confidence interval). An ergonomic tool with improved predictive ability (increased sensitivity and specificity) would be of great utility to workplaces with significant MMH risk factors.

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2. THE REVISED NIOSH LIFTING EQUATION

The Revised NIOSH Lifting Equation is used to evaluate MMH tasks, specifically two-handed lifting tasks (Waters et al., 1993). It produces a recommended weight limit (RWL) at the origin and destination of lift based on the simple product of six measured variables and one constant term. The lesser of the two recommended weights (origin or destination) is used.

The equation is

$$\mathrm{RWL} = \mathrm{LC} \times \mathrm{HM} \times \mathrm{VM} \times \mathrm{DM} \times \mathrm{AM} \times \mathrm{FM} \times \mathrm{CM},$$

where LC—load constant: a constant term equal to 23 kg (51 lbs); HM—horizontal multiplier: based on the horizontal distance from the ankles to the load; VM—vertical multiplier: based on the vertical position (height) of the load at the origin and destination; DM—distance multiplier: based on the vertical distance through which the load is moved; AM—asymmetry multiplier: based on the degree of twisting of the torso; FM—frequency multiplier: based on the frequency and duration of lifting; CM—coupling multiplier: based on the grip or interface between the lifted object and the lifter.

Each measured multiplier (all of the aforementioned except LC) has a range between 0 and 1. Therefore, the greatest recommended weight limit (RWL) would be 23 kg (51 lbs) and the least would be 0 (indicating that a specific lifting task should not be done). The actual object weight is then compared to this RWL to produce a Lifting Index (LI). LI—Actual Object Weight/RWL.

NIOSH considers lifts with a lifting index greater than 1.0 to “pose an increased risk for lifting-related low back pain for some fraction of the workforce” (Waters et al., 1994, p. 34) and that “nearly all workers will be at an increased risk of work-related injury when performing highly stressful lifting tasks (i.e., lifting tasks that would exceed a LI of 3.0)” (Waters et al., 1994, p. 35). The goal is to design lifting tasks such that the LI is less than 1.0.

When multiple tasks are involved, a composite lifting index (CLI) is computed for the overall job. The CLI is computed by taking the largest (worst) individual lifting index and adding to it incrementally based on the lifting indices of the other tasks modified by the relative frequencies of the tasks. The method is somewhat complicated and requires math skills that may preclude its use by some individuals. Computers, however, may assist in this calculation.

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3. NIOSH LIFTING EQUATION LIMITATIONS

The Revised NIOSH Lifting Equation was designed to assess the physical stress associated with two-handed manual lifting tasks. Its application assumes the following conditions:

1. Other manual handling activities are minimal and do not require significant energy expenditures. For example, pushing, pulling, carrying, walking, and climbing activities do not account for more than about 10% of the total work activity.
2. Unpredicted conditions, such as unexpectedly heavy loads, slips, or falls are not present.
3. One-handed lifting, lifting while seated or kneeling, or lifting in constrained workspaces does not occur.
4. An adequate worker-floor coupling (coefficient of friction) is present.
5. The RNLE assumes that lifting and lowering have the same risk.

Most of these assumptions are reasonable for a survey tool. No current ergonomic tools can adequately measure and account for unexpectedly heavy loads, poorly defined, or complex environmental interactions simultaneously. Other investigators have developed comprehensive models accounting for such variables as pushing, pulling, carrying, task duration, ambient temperature, body weight, and age group (Grieco et al., 1997; Hildago et al., 1997;

Shoaf et al., 1997). Some of these models can be demanding, difficult, and time consuming to apply, and most require specialized training or education to use.

4. MATERIALS AND METHODS

Data were analyzed from a database consisting of 667 manufacturing jobs collected from the automotive industry in a prior study. The database included historical injury data for the analyzed jobs as well as symptom interviews and basic medical exams for approximately 1,100 participants. Ergonomic data were quite extensive, with jobs analyzed at the task and subtask level. As there was no personal information linking participants to the jobs studied, approval for accessing the database was granted by both the automotive company and its union representation.

Ergonomic data for the database were collected at six different automotive plants. The plants included: a component plant producing throttle bodies, small electric motors, and small component cast aluminum housings; a vehicle assembly plant building light pickup trucks and sport utility vehicles; a heater and air conditioner components plant; an engine assembly plant making six-cylinder engines; a transmission assembly plant; and a metal stamping plant making large body panels, trunks, hoods, and doors.

Jobs that were not primarily related to manufacturing, such as administrative jobs or jobs that did not have well defined tasks or relatively short cycle times, such as trouble-shooters and maintenance personnel, were not analyzed.

The RNLE load variables for horizontal distance, vertical distance, coupling, and distance traveled were measured directly. The frequency of lifting was computed based on the cycle time of the task and the number of repetitions that occurred per cycle. For example, lifting that occurred every 10 min (10-min cycle time) and included 5 lifts (5 repetitions per cycle) resulted in a frequency of 0.5 lifts/min (5 lifts/10 min). The angle of asymmetry and the corresponding asymmetry multiplier were estimated based on the position of the lifter’s hands (front, front-side, side, or rear).

In addition to the data required to produce the RNLE outputs, a number of generic ergonomic data variables were collected. These data were used to explore other simple methods for estimating low back risk.

The parent automotive company maintains occupational injury data. The company uses the injury database to perform occupational medical surveillance of its manufacturing facilities and to identify of areas or departments

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where injuries may be a problem. Injury data used in this study were historical and included low back related first-time medical visits for a 1-year period retrospectively from the date of the data collection.

Ergonomics data were then analyzed based on biomechanically, physiologically, and logically plausible risk factors identified by the researchers in the literature review. Ergonomic risk factor data have been computed for the subset of tasks involving manual materials handling, specifically lifting. Data were analyzed to determine if some aspects of the current NIOSH lifting equation could be modified to produce a simplified lifting model that performs as well as the existing NIOSH equation.

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5. RESULTS

The RNLE was applied to jobs where appropriate lifting tasks were present (182 jobs). Corresponding injury data were available for 181 of those jobs. The RNLE was able to predict back injuries with odds ratios of 2.1 (1.0–4.3, 95% confidence interval) and 4.0 (1.5–10.3, 95% confidence interval) for lifting indices of 1.0 and 3.0, respectively. In a similar study (Marras, Fine, Ferguson, & Waters, 1999), the Revised NIOSH Lifting Equation was found to be predictive of low back disorders with an odds ratio of 3.1 (2.6–3.8, 95% confidence interval) when comparing high risk ($LI \geq 3.0$) and low risk ($LI \leq 1.0$) jobs. It demonstrated a sensitivity of .73 (identifying jobs with low back morbidity) and a specificity of .55 (identifying jobs without low back morbidity).

When using a lifting index of 1.0 as the cut point, good sensitivity (.76) was achieved, but specificity (.40) was poor. These results are similar to previous research where a sensitivity of .73 and a specificity of .55 were found (Marras et al., 1999). When a lifting index of 3.0 was used as the cut point, sensitivity dropped to .22 and specificity increased to .93. These data are shown in Table 1.

TABLE 1. Revised NIOSH Lifting Equation (a Composite Lifting Index, CLI)

Lifting Index	Odds Ratio	95% CI	Sensitivity	Specificity
1.0	2.1	1.0–4.3	.76	.40
3.0	4.0	1.5–10.3	.22	.93

Notes. CI—confidence interval.

Other research has suggested that the most important variables in predicting the risk of injury are the horizontal distance, the lifting frequency, and the vertical position of the load (Herrin et al., 1986; Marras et al., 1995, 1999; Norman et al., 1998; Shoaf et al., 1997). Therefore, RNLE was computed using only the load constant, horizontal multiplier, vertical multiplier, and frequency multiplier. Omitting the distance multiplier, asymmetry multiplier, and coupling multiplier had little effect on the performance of the RNLE. Prediction of back injury remained good as can be seen by a comparison of Table 2 with Table 1. This supported the idea that simpler methods of estimating lifting risk could be found without a significant decrement in performance.

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TABLE 2. Revised NIOSH Lifting Equation without Distance, Asymmetry, and Coupling Multipliers (Composite Lifting Index, CLI)

Lifting Index	Odds Ratio	95% CI	Sensitivity	Specificity
1.0	2.2	1.1–4.6	.73	.45
3.0	5.3	1.5–19.1	.14	.97

Notes. CI—confidence interval.

Of the 667 automotive jobs in the database, a total of 274 jobs required lifting of some sort. Of these, 182 jobs (66%) had tasks with lifts capable of analysis with the Revised NIOSH Lifting Equation. In addition, 26 of the 182 jobs with tasks capable of RNLE analysis had additional lifting tasks within the job not capable of analysis with the RNLE (e.g., one-handed lifts or hands with differing loads or positions). It is unknown how the risk contributed by these non-RNLE applicable tasks would change the RNLE results. Therefore, only 56% (156) of the 274 lifting jobs were actually used for initial analysis with the RNLE. It is the intention of this research project to increase the number of jobs for which a risk assessment can be conducted. Of the 274 jobs with lifting tasks, 254 had reliable health outcomes that could be used in this analysis.

6. PROPOSED MODIFICATIONS

Inability to analyze jobs with one-handed tasks is viewed as a major drawback of the current RNLE. Levender et al. (1999) also explored the utility of the RNLE in measuring one-handed lifts. Their rationale was to include many manufacturing jobs that did not meet the stated limitations of the RNLE.

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Several methods of estimating the RNLE for one-handed and nonsymmetric (e.g., different load or load locations for each hand) two-handed lifts were explored. First, a lifting index (LI) for each hand was computed independently using a load constant of 11.5 kg (25.5 lbs, 23 kg/2). The two indicators were then combined to produce an effective lifting index for each task. Two major combination methods were investigated: (a) averaging the LIs of each of the hands and (b) taking the maximum LI for either hand. It should be noted that for situations in which the two-handed RNLE would apply, these methods produce identical results. Taking the maximum hand LI may overestimate the risk associated with one-handed lifts, but it was hypothesized that the awkward posture and asymmetric load associated with one-handed lifts can present risks similar to those produced by two-handed LIs of the same magnitude. After computing task level risk, individual tasks must be combined to produce an estimate of the cumulative job level risk. This can be done using the CLI method described by the NRLE. However, combination of multiple tasks in a job using the RNLE can become complicated, particularly when there are three or more lifting tasks to analyze. Therefore, several new methods of combining multiple tasks were considered. The first method investigated assigned the job the highest individual task LI. Two maximum-task methods were explored in this study: (a) simply using the maximum individual hand LI and (b) using the task with the maximum average LI of individual hands. Results are presented in Table 3.

TABLE 3. Individual Hand Analysis Maximum Task Lifting Index (LI)

Model	Lifting Index	Odds Ratio	95% CI	Sensitivity	Specificity
maximum LI for all tasks^1	1.0	2.3	1.1–4.5	.81	.34
maximum LI for all tasks^1	3.0	2.6	1.2–5.2	.25	.88
maximum average LI for all tasks^2	1.0	2.0	1.0–3.9	.78	.36
maximum average LI for all tasks^2	3.0	2.8	1.3–6.1	.20	.92

Notes. 1—maximum task LI, where each task LI is the greater of the left and right individual hand LIs for that task, 2—maximum task LI, where each task LI is the average of the left and right individual hand LIs for that task, CI—confidence interval.

Several methods for computing job level risk using all of the individual lifting tasks (rather than the maximum task alone) were also explored. They included averages and frequency-weighted averages across all tasks using the maximum individual hand LI and the average individual hand LI for each task. Results are presented in Table 4.

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TABLE 4. Averaging of Individual Task Lifting Indices and Revised NIOSH Lifting Equation (RNLE) Composite Lifting Index (CLI)

Model	Lifting Index	Odds Ratio	95% CI	Sensitivity	Specificity
average of maximum individual LI[1]	1.0	2.0	1.0–3.9	.78	.36
average of maximum individual LI[1]	3.0	2.7	1.2–5.8	.22	.91
average of average individual LI[2]	3.0	3.1	1.4–7.3	.19	.93
frequency weighted average of maximum individual LI[3]	1.5	2.1	1.2–3.7	.56	.62
frequency weighted average of average individual LI[4]	2.0	2.2	1.1–4.2	.30	.84
frequency weighted average of average individual LI[4]	3.0	3.4	1.5–8.1	.19	.94
NIOSH Lifting Equation (CLI)[5]	1.0	2.1	1.0–4.3	.76	.40
NIOSH Lifting Equation (CLI)[5]	3.0	4.0	1.5–10.3	.22	.93

Notes. 1—average of the task Lifting Indices (LIs), where each task LI is the greater of the left and right individual hand LIs for that task, 2—average of the task LIs, where each task LI is the average of the left and right individual hand LIs for that task, 3—frequency-weighted average of the task LI, where each task LI is the greater of the left and right individual hand LIs for that task, 4—frequency-weighted average of the task LI, where each task LI is the average of the left and right individual hand LIs for that task, 5—the RNLE CLI for all jobs with only two-handed symetric lifts, CI—confidence interval.

TABLE 5. Weights Lifted as Measure of Lifting Risk

Model	Cut Point	Odds Ratio	95% CI	Sensitivity	Specificity
lift 18 or more kilograms (40 lbs)	at least once	2.1	0.9–4.8	.17	.91
lift 18 or more kilograms (40 lbs)	more than 5 times	2.2	0.9–5.1	.16	.92
lift 4.5 or more kilograms (10 lbs)	more than 500 times	1.6	0.9–2.9	.45	.62
lift 4.5 or more kilograms (10 lbs)	more than 1,000 times	1.7	0.9–3.2	.28	.81
total weight lifted per day	9,000 kg (20,000 lbs)	2.4	1.3–4.7	.31	.84

Notes. CI—confidence interval.

Some simple, intuitive measures of biomechanical risk were also collected as part of the original data set. These included the number of times that a given weight threshold was exceeded (i.e., times per day that 18 or more kilograms [40 lbs] was lifted), the number of kilograms lifted per day (simple total of all weights from all lifting tasks), number of times that a given moment threshold was exceeded (i.e., times per day that a 22.6 N· m [200 in.-lb] moment was generated about the low back), and the horizontal distance (HD) multiplied by both the object weight (Wt) and number of lifts per day (HD × Wt × lifts/day). These results are presented in Tables 5 and 6.

TABLE 6. Load Generated Moments as a Measure of Lifting Risk

Model	Cut Point	Odds Ratio	95% CI	Sensitivity	Specificity
22.6 N· m moment (200 in.-lb moment)	more than 1,000 times	1.9	1.0–3.3	.44	.71
33.9 N· m moment (300 in.-lb moment)	more than 1,000 times	2.1	1.1–3.9	.36	.79
45.2 N· m moment (400 in.-lb moment)	more than 1,000 times	2.3	1.1–4.9	.23	.88
Horizontal distance × weight × lifts	56,500 m-NT-lifts (500,000 in.-lb-lifts)	2.3	1.5–4.4	.30	.84

Notes. CI—confidence interval.

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7. PERFORMANCE OF PROPOSED TOOL

The application of the RNLE concept to individual hands produced results very similar (identical for two-handed symmetric lifts) to those obtained when applying the RNLE to two-handed symmetric lifts only, such as the RNLE model intended. This is important as the number of jobs with lifting tasks that could be analyzed increased from 156 (182 had two-handed lifting tasks, but only 156 had only two-handed symmetric lifting tasks) to 274.

Choosing only the maximum individual hand LI across all tasks (full LI used for one-handed lifts) produced significant odds ratios. A sensitivity of .81 was achieved at a 1.0 LI cut point and a specificity of .88 was produced at a 3.0 LI cut point. Using the maximum average LI across all tasks (average LI used, one-handed lifts were averaged with 0 for the other hand) also produced significant results. These results are summarized in Table 3.

Averaging and frequency-weighted averaging of tasks produced significant odds ratios that warrant further investigation. These methods are less complicated than the CLI for the combination of individual tasks to a job level risk score. Averages across tasks were computed using both average LI scores (both hands averaged) and maximum individual hand LI scores (full

LI used for one-handed lifts). Frequency weighted averages were also computed for individual task average and maximum LI scores. These results are summarized in Table 4.

The number of times that a particular threshold weight was exceeded during lifting activities was not found to be a statistically significant predictor of back injury. Odds ratios were generally poor and the 95% confidence intervals included 1.0. The total weight lifted per day, however, was related to back injury. Typical results are shown in Table 5.

Summing the number of times that a particular moment threshold was exceeded was more promising than a simple sum of the weights lifted. Also, the sum of the actual moments (horizontal distance × weight associated with each lift) multiplied by the number times per day they occurred (HD × Wt × lifts/day) was predictive. Typical results are shown in Table 6.

Removing the frequency multiplier and summing the value Frequency Independent Lifting Index (FILI) × the number of lifts per day for each task also demonstrated significant odds ratios. This was done for two-handed lifts (done as a standard RNLE analysis without frequency multiplier) and for one- and two-handed lifts (RNLE concept applied to each hand and maximum used for each task). This simpler method of combining multiple tasks also warrants further research. These results are shown in Table 7.

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TABLE 7. Frequency Independent Lifting Index (FILI) Multiplied by Lifts per Day (L/D)

Model	Cut Point	Odds Ratio	95% CI	Sensitivity	Specificity
FILI × L/D (1 or 2 hands)	more than 1,000	1.8	1.0–3.3	.38	.75
FILI × L/D (2 hands only)	more than 10,000	2.7	1.3–5.8	.33	.85

Notes. CI—confidence interval.

8. DISCUSSION AND LIMITATIONS

The omission of specific lift characteristics from the RNLE did not appear to hinder the performance of the NIOSH model for either high- or low-risk job tasks. The sensitivity and specificity were nearly identical at .76 and .40 compared to .73 and .45 when the LI was 1.0. When the LI was increased to 3.0, sensitivity and specificity were .22 and .93 compared to .14 and .97 respectively. These findings are promising. Marras et al. (1999) evaluated the RNLE against two databases with known outcomes and found similar results.

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The literature strongly supports those characteristics that reflect stress to the back as indicators of increased risk (NIOSH, 1997).

In the original automotive study, data were collected to satisfy many ergonomic tools. Where possible, these data were measured and collected specifically as prescribed by each ergonomic tool. However, due to logistical constraints, mostly associated with limited on-site time, some ergonomic data were collected in a manner slightly different than the original authors may have stipulated or anticipated. In this study, the angle of asymmetry was not measured directly, but was estimated based on hand position. Whereas the authors do not believe that these differences in data collection would substantially alter RNLE asymmetry multipliers and therefore outputs, this may have produced a systematic misclassification.

The automotive company's health and employment data were not always maintained at a level adequate to determine with certainty which job in a department or area was the cause of an injury. Data were coded to reflect the level of certainty of relationship with the study jobs. Only those jobs for which the researchers, after consultation with area supervisors, were reasonably certain of the relationship of an injury were used in the analysis. Whereas it is possible that some jobs were misclassified with regard to injury status, it is believed that there was no systematic misclassification and that the effects of possible misclassification were random. In addition, the transfer of injured workers from relatively stressful jobs to less stressful jobs may also result in some error as the healthiest or strongest workers may be placed on the more stressful jobs (healthy worker effect). These limitations are present in virtually all work places and the RNLE still performed well given this potential for misclassification.

The requirement of the RNLE that lifts be made with two-hands is limiting (only 56% of jobs fell within RNLE CLI guidelines). There are many lifting tasks that require one-handed lifting or lifting two separate items simultaneously. In addition, workstation layout or worker preference (or desire to maintain production speed) may encourage a one-handed rather than a two-handed lift. A model that incorporates both two-handed and one-handed lifts would therefore be more useful for predicting injuries.

The proposed methods (maximum and average individual hand LIs) for evaluating one-handed lifts provide options for evaluating additional MMH tasks, thereby adding to the utility of the modified RNLE.

Poor tool performance may be seen as high sensitivity and low specificity, which may result in misdirected allocation of resources to abate ergonomic hazards that do not really exist. The goal is to develop an easy-to-use MMH evaluation tool with both high sensitivity and high specificity to correctly identify risk and necessary ergonomic controls and, equally important, to identify those job tasks not needing costly modification.

9. CONCLUSIONS AND RECOMMENDATIONS

Based on these results, it appears that the RNLE can be modified to allow analysis of one-handed and two-handed asymmetric lifts without hindering performance. This will greatly increase the applicability of the model allowing analysis of many additional manual materials handling tasks. The model can also be simplified without significant loss of predictive ability. Simplifying the model may also increase its application by improving the accessibility of the model to more users. It was demonstrated that alternative methods for aggregating multiple tasks into a single index could perform comparably to the current NRLE method (computing the CLI). Work is progressing in these areas with the goal to produce a simplified RNLE-type equation that can be applied quickly and easily in a greater variety of workplaces and for a greater variety of lifting tasks.

The Revised NIOSH Lifting Equation has demonstrated significant odds ratios for the prediction of low back injuries. The results of this study suggest that a simplified NIOSH equation, using a sub-set of the NIOSH variables and requiring less computation, can perform nearly as well as the full NRLE model.

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