Can the Revised NIOSH Lifting Equation Be Improved by Incorporating Personal Characteristics?

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Abstract. The impact of manual material handling such as lifting, lowering, pushing and pulling have been extensively studied. Many models using these external demands to predict injury have been proposed and employed by safety and health professionals. However, ergonomic models incorporating personal characteristics into a comprehensive model are lacking. This study explores the utility of adding personal characteristics such as the estimated L5/S1 Intervertebral Disc (IVD) cross sectional area, height, age, gender and Body Mass Index (BMI) to the Revised NIOSH Lifting Equation (RNLE) with the goal to improve injury prediction. A dataset with known RNLE Cumulative Lifting Indices (CLIs) and related health outcomes was used to evaluate the impact of personal characteristics on RNLE performance. The dataset included 29 cases and 101 controls selected from a cohort of 1,022 subjects performing 667 jobs. RNLE performance was significantly improved by incorporation of personal characteristics. Adding gender and intervertebral disc size multipliers to the RNLE raised the odds ratio for a CLI of 3.0 from 6.71 (CI: 2.2–20.9, PPV: 0.60, NPV: 0.82) to 24.75 (CI: 2.8–215.4, PPV: 0.86, NPV: 0.80). The most promising RNLE change involved incorporation of the multiplier based on the estimated IVD cross-sectional area (CSA). This multiplier was developed by normalizing against the IVD CSA for a 50th percentile woman. This multiplier could assume values greater than one (for subjects with larger IVD CSA than a 50th percentile woman). Thus, CLI could both decrease and increase as a result of this multiplier. Increases in RNLE performance were achieved primarily by decreasing the number of RNLE false positives (e.g., some CLIs for uninjured subjects were reduced below 3.0). Results are promising, but confidence intervals are broad and additional, prospective research is warranted to validate findings.

Keywords: Revised NIOSH Lifting Equation (RNLE) · Personal characteristics · BMI · Age · Gender · Low back pain · Intervertebral disc cross sectional area · L5/S1

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1 Introduction

Musculoskeletal disorders (MSDs) are a major burden on individuals, health systems and social care systems, with indirect costs being predominant, and their impact is pervasive [1]. MSDs affect hundreds of millions of people around the World and the most common MSD is low back pain (LBP) which is the leading cause of activity limitation and work absence [2]. It has been recognized that low back pain (LBP) risk is associated with a combination of personal factors, psychological or psychosocial factors, as well as physical exposures [3]. Several case-control studies have revealed that high BMI (overweight) has a significant association with low back pain [4, 5]. According to a systematic review, heavy physical work, awkward postures, lifting, psychosocial factors, BMI and age all have a strong impact on low back pain [6].

Several risk assessment tools have been developed to evaluate LBP risk resulting from manual material lifting tasks. The most well-known and widely–used tool among the ergonomics community is the Revised NIOSH Lifting Equation (RNLE) [7–14]. However, most ergonomic assessments do not consider personal characteristics directly, rather, they focus on physical factors associated with the job demands. Suggestions have been made on how to modify the equation or multipliers used in the equation to improve its reliability, better estimate stressors faced by varying populations, expand the functionality, or simplify the RNLE [15–17].

This research explores the potential impact of these factors and proposes several ways to incorporate such characteristics into the RNLE. Specifically, multipliers were created to explore age, gender, BMI, and a scaling factor based upon intervertebral disc diameter.

2 Methodology

This paper modified the RNLE by considering additional multipliers: including age, gender, Body Mass Index (BMI), intervertebral disc (IVD) cross-sectional area (CSA) and a new coupling multiplier with lower coefficients for non-optimal couplings. A retrospective, case-control methodology was employed to determine the predictive ability of the RNLE and modified RNLE measures. A database was modified to allow multipliers to be "switched on or off" so that various combinations could be explored. First, multipliers were added individually followed by various combinations to determine their impact on model performance. All combinations were evaluated based on odds ratios, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) compared to baseline ("normal") RNLE performance with all six original multipliers in place. All outputs were recorded in tables comparing new models to baseline RNLE data. A database from an epidemiological study [15] involving a large automotive manufacturer was used to explore modifications to the RNLE.

2.1 An Automotive Manufacturing Ergonomic Field Study

The data were collected from six different automotive plants and consist of 667 manufacturing jobs with 1,022 participants as well as job-specific, historical injury data. Well-defined lifting activities meeting the RNLE criteria for analysis (e.g., two-handed, symmetric lifts) were selected for this study. Personal characteristic variables investigated for this study included height, weight, age and gender and self-reported ratings of perceived discomfort. Subjects were asked to report their LBP discomfort on the day they were interviewed as well as to report any LBP symptoms for the previous year. Cases were defined as subjects who had both LBP symptoms in the previous year and whose job had one or more LBP-related medical visits in the previous year. There were 130 subjects meeting all inclusion criteria: 29 cases and 101 controls. The subject population was composed of 101 males and 29 females aged 23–65 (mean 42 ± 11.2 years), heights from 59-76 inches (mean 69.5 ± 3.6), weights from 115–350 lb (mean 191 ± 45.1), and Body Mass Index from 17.0 to 54.8 kg/m^2 (mean 27.6 ± 5.6). The prevalence of low back pain for this population was 22% (29/130).

2.2 A Morphometric Study of Low Back Geometry Using MRI Technology

Previous research has yielded a regression equation to predict the size of an individual's IVD cross-sectional area [17, 18]. That study used subjects without current or chronic episodes of LBP and examined them using a whole body 3T Magnetic Resonance Imaging machine (Siemens Verio open-bore). The IVD cross-sectional area used for this study [18] was the L5/S1 IVD measured at its center (see Line "B" in Fig. 1 below).

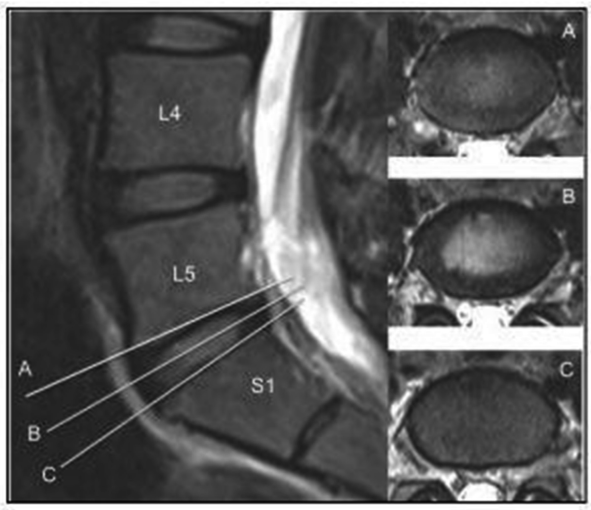

Fig. 1. Sample of MRI scan in sagittal and transverse planes [18]

IVD area was used to scale risk up or down for smaller and larger subjects, respectively. A 50th percentile female IVD area was used to normalize risk. Subjects with smaller estimated IVD areas were considered at higher risk and those with larger

IVD areas were considered to be at lower risk. The IVD multiplier could have been normalized to any size disc but was targeted to a smaller than average size to account for false positives common with the RNLE.

$$\mathbf{L5/S1\,IVD\,CSAs} = [-\mathbf{16.959} + \mathbf{0.179} * \mathbf{Height} * \mathbf{2.54} + \mathbf{1.7} * \mathbf{Gender}]\,\mathbf{cm^2}$$
$$(\mathbf{Gender}\,(\mathbf{G}) = \mathbf{0\,for\,females\,and\,1\,for\,males})$$

3 Experimental Design

Modifications to the RNLE were proposed and several novel multipliers were selected for evaluation. These multipliers are gender (GM), body mass index (BMIM), age (AGEM), an approximation of the low back intervertebral disc (IVD) size (IVDM).

$$\mathbf{IVDM} = \mathbf{Subject\,L5/S1\,IVD\,Area\,/\,50th\,percentile\,female\,L5/S1\,IVD\,Area}$$

A new, more conservative CM was also proposed and tested. The RNLE uses the following multipliers “good coupling” = 1.0, “fair coupling” = 0.95, and “poor coupling” = 0.90. The proposed new coupling multiplier (NCM) uses 1.0, 0.80, and 0.70 for good, fair, and poor couplings, respectively. A gender multiplier (GM) of 2/3 was applied to female subjects as proposed in the *Applications Manual for the Revised NIOSH Lifting Equation* [10]. Males were assigned 1.0 for GM. A BMI multiplier (BMIM) was applied to penalize subjects whose BMI was greater than 30. The BMIM consisted of 30/BMI for BMIs > 30 and 1.0 for BMIs less than or equal to 30. An age multiplier (AGEM) to account for strength losses expected from aging was also tested. The age multiplier was 1.0 for subjects under the age of 40 and decreased by 1% (0.01) for each year of age beyond 40.

To evaluate RNLE multipliers, a LI of 3.0 was used to classify jobs as more or less risky. All new multipliers were tested individually and in groups to see if predictions could be improved for the RNLE CLI. The new multipliers work just as the original multipliers and can be easily included in the RWL calculations as shown in below:

$$\mathbf{RWL} = \mathbf{LC\,x\,HM\,x\,VM\,x\,DM\,x\,AM\,x\,FM\,x\,CM\,x\,GM\,x\,BMIM\,x\,AGEM\,x\,IVDM}$$

Modifications to the RNLE were proposed to account for an increasingly diverse, aging, and obese population of workers.

4 Results

Table 1 shows the impact of adding personal multipliers to the RNLE compared to the baseline (original) RNLE CLI. Each column represents the addition of a single multiplier to the baseline RNLE.

Table 1. Addition of new personal multipliers

	CLI (Baseline)	+BMIM	+AGEM	+GM	+IVDM
Odds Ratio	6.71	6.71	6.71	7.83	19.8
(95% CI)	(2.2–20.9)	(2.2–20.9)	(2.2–20.9)	(2.6–24.0)	(2.2–177.2)
p-value	0.0057	0.0057	0.0057	0.0015	0.0073
Sensitivity	0.30	0.30	0.30	0.33	0.17
Specificity	0.94	0.94	0.94	0.94	0.99
PPV	0.60	0.60	0.60	0.63	0.83
NPV	0.82	0.82	0.82	0.82	0.80

The IVD multiplier (IVDM) had the greatest impact on the RNLE, significantly improving overall odds ratio. However, the sensitivity dropped substantially (from .30 to .17). The GM modestly improved the odds ratio and overall model performance. The addition of an AGEM or BMIM did not alter the RNLE. Next, multipliers were added in combinations to see if RNLE performance could be further increased. Table 2 and 3 illustrate the impact of various combinations of proposed multipliers, ranging from lower to higher performance.

Table 2. Combinations of new multipliers

	CLI (Baseline)	+BMIM +AGEM	+BMIM +AGEM +GM	+GM +AGEM/ +BMIM +GM	+IVDM +AGEM
Odds Ratio	6.71	4.33	4.5	6.64	9.8
(95% CI)	(2.2–20.9)	(1.5–12.2)	(1.7–12.3)	(2.3–19.6)	(1.8–53.5)
P-value	0.0010	0.0057	0.0032	0.0006	0.0084
Sensitivity	0.30	0.30	0.33	0.33	0.17
Specificity	0.94	0.91	0.90	0.93	0.98
PPV	0.60	0.50	0.50	0.59	0.71
NPV	0.82	0.81	0.82	0.82	0.80

RNLE performance was maximized by adding both the IVDM and GM. The IVDM had the greatest impact and combinations that included it performed the best. An odds ratio near 25 was achieved by combining the IVDM and the GM. It should be noted, however, that sensitivity remained significantly lower than baseline with performance (odds ratio; improvements coming from the reclassification of false positives as true negatives. Also, the confidence interval, while significant, is very large (2.8–215.4). Unlike all of the other multipliers, the IVDM can actually reduce estimated risk; reducing some over-estimation of risk.

Table 3. Combinations of new multipliers

	CLI (Baseline)	+GM +AGEM +BMIM +IVDM	+BMIM +IVDM +GM or +BMIM +IVD +AGEM or +IVDM +AGEM +GM	+BMIM +IVDM	+IVDM +GM
Odds Ratio	6.71	9.84	12.25	19.80	24.75
(95% CI)	(2.2–20.9)	(2.4–41.0)	(2.3–64.5)	(2.2–177.2)	(2.8–215.4)
P-value	0.0010	0.0017	0.0031	0.0076	0.0036
Sensitivity	0.30	0.23	0.20	0.17	0.20
Specificity	0.94	0.97	0.98	0.99	0.99
PPV	0.60	0.70	0.75	0.83	0.86
NPV	0.82	0.81	0.80	0.80	0.80

5 Discussion

This research indicates that personal characteristics can be successfully and simply factored into ergonomic assessment tools such as the RNLE to improve their performance. Further, some factors may be removed from tools without a decrement in performance. In the case of the RNLE, personal characteristics may even be integrated after job level data collection to improve risk estimation for individuals.

This study demonstrates that model performance cannot solely be assessed by univariate analyses. Various combinations of multipliers should be explored to determine the best performing models. This is particularly true for the traditional multipliers, all of which can hold maximum values of 1.0. In other words, risk estimates increase (or stay the same) when these multipliers are employed. The IVDM, on the other hand, can increase or decrease risk since it can have values both less than and greater than 1.0. Future work should consider other multipliers that can hold values greater than 1.0 and/or consider modifying existing multipliers to allow values above 1.0. Multipliers exceeding 1.0 may especially help to minimize false positive classifications.

While model performance was significantly enhanced by incorporating personal characteristics, model sensitivity (detecting cases) was relatively low and was, in fact, lower than the baseline sensitivity in the best performing models (sensitivity reduced from .3 to .2). While positive predictive value (PPV) was relatively high, with 86% of subjects with CLIs over 3.0 properly identified as cases, only 1 in 5 cases; however (.2), were identified using the new RNLE model (+IVDM, +GM). More research is needed to produce effective models. However, ergonomists can also alter decision points to impact sensitivity. For example, Table 4 below shows the impact of reducing the CLI decision cut-point from 3.0 to 2.5.

Table 4. RNLE model with new multipliers and reduced CLI Cut-point of 2.5

	CLI (Baseline)	+IVDM +GM
Odds Ratio	6.71	10.29
(95% CI)	(2.2–20.9)	(2.9–36.6)
P-value	0.0010	0.0003
Sensitivity	0.30	0.30
Specificity	0.94	0.96
PPV	0.60	0.69
NPV	0.82	0.82

Sensitivity returned to 0.30 (baseline) along with modest improvements to specificity and PPV.

6 Conclusion

Personal characteristics appear to drive a significant proportion of manual material handling (MMH) risk and should be considered when assessing MMH risk. Models incorporating a subject's estimated intervertebral disc size were the most promising and should be explored further. This study demonstrated the potential value of including these personal characteristics on diverse set of subjects and lifting tasks from 6 different automotive manufacturing sites. The subjects included a wide range of ages, BMIs, and were comprised of 22% female workers. Likewise, future research should also include subject populations that are as diverse as possible, particularly since the workforce is aging and increasingly obese. Identifying the contributions of obesity to MMH risk may further demonstrate the value of wellness programs aimed at assisting workers in maintaining healthy lifestyles and physical conditions.

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References

1. Woolf AD, Pfleger B (2003) Burden of major musculoskeletal conditions. Bull. World Health Organ. 81(9):646–656
2. Lidgren L (2003) The bone and joint decade 2000–2010. Bull. World Health Organ. 81 (9):629
3. Institute of Medicine and National Research Council (2001) Musculoskeletal disorders and the workplace. The National Academies Press, Washington, DC

4. Shiri R, Karppinen J, Leino-Arjas P, Solovieva S, Varonen H et al (2007) Cardiovascular and lifestyle risk factors in lumbar radicular pain or clinically defined sciatica: a systematic review. Eur. Spine J. 16:2043–2054
5. Schumann B, Bolm-Audorff U, Bergmann A, Ellegast R, Elsner G et al (2010) Lifestyle factors and lumbar disc disease: results of a German multi-center case-control study (EPILIFFT). Arthritis Res Ther 12:193
6. Da Costa BR, Vieira ER (2010) Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies. Am. J. Ind. Med. 53:285–323
7. Dempsey PG (2002) Usability of the revised NIOSH lifting equation. Ergonomics 45 (12):817–828 Liberty Mutual Research Center for Safety & Health, 71 Frankland Road, Hopkinton, Massachusetts 01748, USA
8. Dempsey PG, McGorry RW, Maynard WS (2005) A survey of tools and methods used by certified professional ergonomists. Appl Ergon 36:489–503
9. Waters TR, Putz-Anderson V, Garg A, Fine L (1993) Revised NIOSH equation for design and evaluation of manual lifting tasks. Ergonomics 36(7):446–749
10. Waters TR, Putz-Anderson V, Garg A (1993) Applications manual for the revised NIOSH lifting equation. US Department of Health and Human Services, Cincinnati
11. Waters TR, Putz-Anderson V, Garg A, Fine LJ (1993) Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics 36:749–776
12. Waters TR, Putz-Anderson V, Garg A (1994) 'Applications manual for the revised NIOSH lifting equation' DHHS (NIOSH) Publication No. 94–110, U. S. Department of Health and Human Services, National Institute for Occupational Safety and Health, Cincinnati, OH
13. Gallagher S, Sesek RF, Schall M Jr, Huangfu R (2017) Development and validation of an easy-to-use risk assessment tool for cumulative low back loading: the lifting fatigue failure tool (LiFFT). Appl Ergon 63(142–150):13
14. Garg A (1995) Revised NIOSH equation for manual lifting: a method for job evaluation. AAOHN J 43(4):211–216
15. Sesek RF (1999) Evaluation and refinement of ergonomic survey tools to evaluate worker risk of cumulative trauma disorders. Doctoral Dissertation. University of Utah, Salt Lake City, UT
16. Sesek R, Gilkey D, Drinkaus P, Bloswick DS, Herron R (2003) Evaluation and qualification of manual materials handling risk factors. Int J Occup Saf Ergon 9(3):271–287
17. Sesek R, Tang R, Gungor C, Gallagher S, Davis GA, Foreman KB (2014) Using MRI-derived spinal geometry to compute back compressive stress (BCS): a new measure of low back pain risk. In: Duffy V (ed) Proceedings of the 5th AHFE Conference, pp 13–18
18. Tang R (2013) Morphometric analysis of the human lower lumbar intervertebral discs and vertebral endplates: experimental approach and regression models. Doctoral Dissertation. Auburn University, Auburn, AL