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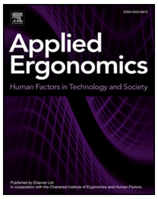

Improving the risk assessment capability of the revised NIOSH lifting equation by incorporating personal characteristics

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ABSTRACT

The impact of manual material handling such as lifting, lowering, pushing, pulling and awkward postures have been studied, and models using these external demands to assess risk of injury have been developed 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, age, gender and Body Mass Index to the Revised NIOSH Lifting Equation (RNLE) with the goal to improve risk assessment. 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 1022 subjects performing 667 jobs. RNLE risk assessment was 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) to 24.75 (CI: 2.8–215.4). Similarly, performance was either unchanged or improved when some existing multipliers were removed. The most promising RNLE change involved incorporation of a multiplier based on the estimated IVD cross-sectional area (CSA). Results are promising, but confidence intervals are broad and additional, prospective research is warranted to validate findings.

1. Introduction

"Musculoskeletal disorders (MSDs) were recognized as having occupational etiologic factors as early as the beginning of the 18th century. However, it was not until the 1970s that occupational factors were examined using epidemiologic methods, and the work-relatedness of these conditions began to appear regularly in the international scientific literature" (Bruce et al., 1997).

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 (National Research Council, 2001). da Costa and vieira (2010) conducted a systematic review to evaluate the risk factors for work-related musculoskeletal disorders for the neck, shoulder, wrist/hand, low back, hip, knee, ankle and feet. da Costa et al.'s review supports that heavy physical work, awkward postures, lifting, psychosocial factors, BMI and age all have a strong relationship with LBP. The relationship between occupational LBP and LBP risk factors has been previously investigated primarily in field surveillance studies (Lotters et al., 2003; Marras et al., 1993, 1995a,b; Norman et al., 1998; Punnett et al., 1991; Waters et al., 1999; Bernard, 1997; Hoogendoorn et al., 2000). However, most of these studies have focused almost exclusively on the impact of work demands such as lifting, awkward postures, trunk flexion, heavy weight, force and repetition, static and forceful movements (Marras et al., 1995a,b, 2010a,b; Garg et al., 2013). 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) (Dempsey et al., 2005; Waters et al., 1993a,b,c, 1994; Gallagher et al., 2017). However, most ergonomic assessments do not consider personal characteristics directly, rather, they focus on physical factors associated with the job demands.

Changes to the RNLE have been frequently suggested. However, most of these changes have focused on the physical demands of the job. For example, there have been recent efforts to improve risk determination for jobs with varying lifting demands and to estimate risk for an entire, variable work shift (Garg and Kapellusch, 2016; Waters et al., 2007). Despite these techniques demonstrating good estimations for

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LBP risk at the population level, there remains room for improvement regarding individual risk assessment. Indeed, an inherent limitation of these assessment tools is that they only address the work demands, and ignore the capability of the worker performing these tasks. That is, these tools may be able to assess the risk of work activities to the general population of workers, but not the risk to an individual worker. Identifying the causes of LBP is difficult since its causes are multifactorial and involve personal, physical job factors, and workplace psychosocial characteristics (Davis and Heaney, 2000; Lu et al., 2014). It seems reasonable to investigate the risk assessment capabilities of ergonomic tools, which incorporate not only work demands, but also individual characteristics of the worker performing the job.

The RNLE attempts to assess the risks of LBP resulting from various manual material handling tasks by calculating a recommended weight for specified two-handed, and symmetrical lifting tasks. The RNLE is a job analysis method commonly used to quantify biomechanical stressors to the low back from lifting and lowering of loads in workplaces (Garg et al., 2013). The main objective of the revised equation was to prevent and reduce the occurrence of lifting and lowering overexertion injuries and low back pain among workers (Garg, 1995). An asymmetry (twisting) multiplier (AM) and coupling (grip) multiplier (CM) as well as the concept of a “Lifting Index” (LI) were added to the original (1981) NIOSH Lifting Equation (Waters et al., 1988, Waters et al., 1993a,b,c). In addition to the coupling and asymmetry changes in the revised method, modifications included a 17 kg (37.5 lb) reduction of the load constant, modifications to the horizontal multiplier, modifications to the effect of frequency and replacing multiple limits (the action limit and the maximum permissible limit) by a single limit (recommended weight limit) (Dempsey, 2002).

This equation is accepted as a useful and valuable tool for the design and evaluation of manual lifting impacts to occupational health (Jager and Luttmann, 1999) and it has gained widespread popularity in the United States and internationally as a tool for assessing the physical demands of two-handed manual lifting tasks (Waters et al., 1998). However, variation in the capabilities and limitations of individual workers can render risk assessments inaccurate for many workers. This is particularly true as the workforce changes; more females are entering into traditionally male occupations requiring manual handling and as the US workforce is increasingly obese and aging (Ricci and Chee, 2005). 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 (Sesek et al, 2003, 2014). This research explores the potential impact of these factors and proposes several ways to incorporate these characteristics into the Revised NIOSH Lifting Equation. Specifically, multipliers were created to explore age, gender, BMI, and a scaling factor based upon intervertebral disc diameter.

Sesek et al. (2003) explored the idea of simplifying the RNLE to see if its risk assessment ability for determining workers who are at risk of suffering a low back injury could be maintained while requiring less computation. Those findings suggest that risk assessment performance can be maintained while simultaneously simplifying the assessment effort. The goal of this research is to explore both adding and subtracting multipliers to enhance model performance with the aim of minimizing RNLE user computational burden. In that spirit, the new personal characteristic multipliers can be easily integrated *before or after* RNLE computation. Therefore, existing RNLE data can be modified for specific workers without the need to re-analyze the physical job itself. By considering both adding and subtracting multipliers, models can be explored that potentially have fewer or no net difference in multipliers while exhibiting improved performance.

The RNLE provides an empirical method for computing a recommended weight limit (RWL) for manual lifting. The actual weight lifted is divided by the RWL to create a lifting index (LI).

The LI has been used to estimate risk for developing lifting-related LBP (Liles & Mahajan, 1985; Chaffin and park, 1973; Marras et al., 1999a,b; Waters et al., 2011a,b). Higher LIs are associated with higher risk for LBP. LIs can been used to prioritize jobs for hazard abatement indicating which jobs are generally most difficult. However, not all workers will be at the same risk when performing a given set of lifting tasks. The RNLE does not consider personal differences and how these might impact a specific individual's risk for LBP. The RNLE consists of six multipliers (horizontal multiplier (HM), vertical multiplier (VM), Distance Multiplier (DM), asymmetry multiplier (AM), frequency multiplier (FM), and a coupling multiplier (CM)) and a load constant (LC) of 51 pounds. RWL is simply calculated as the product of all multipliers and the load constant:

2. Methodology

This paper modified the RNLE by considering additional multipliers and the elimination or modification of existing multipliers. New multipliers included: age, gender, Body Mass Index (BMI), IVD cross-sectional area (CSA) and a new coupling multiplier with lower coefficients for non-optimal couplings. The vertical, distance, coupling, and asymmetry multipliers were also considered for elimination. A retrospective, case-control methodology was employed to determine the predictive ability of the RNLE and modified RNLE measures.

The database was modified to allow multipliers to be “switched on or off” so that various combinations could be explored. First, multipliers were added individually to determine their impact on the model. Next, multipliers were added in various combinations to determine their impact on model performance as measured by the association of LI to negative health outcomes. Then, existing multipliers were removed individually and in combinations to measure the impact on model performance. Finally, combinations of both adding and subtracting various multipliers were considered. All combinations were evaluated based on odds ratio, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) as compared to baseline (“normal”) RNLE performance with all six original multipliers in place. All outputs are recorded in tables comparing new models to baseline RNLE data.

A database from an epidemiological study involving a large automotive manufacturer was used to explore modifications to the RNLE. The database included historical injury data and symptom interviews (Sesek, 1999). Personal identifiers such name and date of birth were not included in the data set. Researchers in the current study were blinded to all images and potential identifying information and had data on age, height, weight, and gender only. Information regarding low-back related injuries was known for each subject's job, but not whether that specific individual had reported an injury.

2.1. *An automotive manufacturing ergonomic field study*

The data were collected from six different automotive plants, and consist of 667 manufacturing jobs with 1022 participants as well as job-specific, historical injury data. Well-defined lifting activities meeting the RNLE criteria for analysis (e.g., two-handed lifts that are stable, unconstrained, with good foot/floor coupling, and in favorable environmental conditions) were selected for this study. Administrative jobs or jobs that did not require any lifting tasks or did not have well-defined tasks were not used in this analysis.

Personal characteristic variables investigated for this study included height, weight, age and gender (used to estimate the lower lumbar spinal geometry and compute BMI) 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. In addition, data were available regarding which jobs had one or more LBP-related medical visits during the previous year. Injuries on those jobs may or may not have been to subjects working on those jobs during the data collection. Cases were defined as subjects