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Understanding outcome metrics of the revised NIOSH lifting equation

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ABSTRACT

The interpretation of the calculated result of the revised NIOSH Lifting Equation (RNLE) has been problematic because the relationship of the calculated result to back injury risk has not always been either well understood nor consistently interpreted. During the revision of the ISO standard 11228–1 (Manual lifting, lowering and carrying), an extensive literature review was conducted on validation studies of the RNLE. A systematic review of exposure-risk associations between the LI metrics and various low-back health outcomes from peer-reviewed epidemiological studies was conducted. Risk interpretations for different levels of calculated result of the RNLE are added to the ISO standard. Rationale for the risk interpretations is presented in this paper.

1. Introduction

The NIOSH Lifting Equation, since its initial publication in 1981 (NIOSH, 1981) and its revised publication in 1994 (Waters et al., 1993, 1994) is one of the most frequently used tools applied by occupational ergonomists to assess lifting tasks (Dempsey et al., 2018, 2005). Given that the manual lifting of objects is ubiquitous throughout industrial and service occupations, the revised NIOSH Lifting Equation (RNLE) is used globally and is cited in a number of standards, specifications and guidelines produced by a variety of enterprises, associations and standards-making bodies, including the ISO standard 11228 Part 1: *Manual Lifting and Carrying (*ISO, 2003*)*. Due to this use and given the validation studies, extensions and updates done on the RNLE the 1981 NIOSH Lifting Equation is considered as fully superseded by the RNLE.

Because the RNLE was first introduced to the public at a national conference in 1991, it is sometimes referred to as the 1991 NIOSH Lifting Equation. The terms "Maximum Permissible Limit" and "Action Level" for weight limit in the original equation were replaced by the Recommended Weight Limit (RWL) in the revised version. Two further task variables, trunk asymmetry and hand coupling, were introduced to the revised equation in addition to horizontal and vertical location, travel distance, frequency of lift and duration of lifting work. At the time of publication of the RNLE, the safe level for the two outcome measures of the RNLE, namely the lifting index (LI) and composite lifting index (CLI), was set at 1.0. However, this safe level was considered a theoretical value for the prevention of low back disorders in most workers based on subject matter experts' opinions using the literature available at that time.

As detailed in the applications manuals for the RNLE, the LI and CLI are risk indices for single lifting and multiple lifting tasks, respectively (Waters et al., 1994). As manual lifting tasks increase their complexity in recent decades, the LI and CLI may not be suitable for assessing manual work involving a large number of varying tasks. Hence, researchers have derived new risk measures for complex lifting tasks. These new measures include the Sequential Lifting Index (SLI) for tasks involving job rotation (Waters et al., 2007), the Variable Lifting Index (VLI) for assessing a large number of varying lifting tasks (Waters et al., 2016) and the Cumulative Lifting Index (CULI) for evaluating varying lifting frequency and duration throughout a work shift (Garg and Kapellusch, 2016). The Composite lifting index (CLI), the Sequential Lifting Index (SLI) and the Variable Lifting Index (VLI) are addressed in the revised version of ISO 11228–1 (ISO, 2018).

In the context of physical work hazard exposure assessment, the term "exposure" is defined as the extent to which a worker is subject to a specific magnitude, frequency and duration of job demands during work. The amount of that exposure can be expressed in quantitative terms and can refer to the extent to which a person is subjected to a hazard (potential source of harm) or combination of hazards. In this paper reflecting the standard ISO 11228–1, exposure is referred to as the amount of the combined effect of all job-related physical lifting hazards (i.e., all the variables used in the lifting equation which may present a risk of harm).

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Risk is defined as the combination of the probability of occurrence of harm (e.g. likelihood of having an adverse health outcome such as back pain). In the context of occupational ergonomics, the probability may vary depending on many work-related and personal factors. In this paper, age and gender are included as overall risk variables for a working population. Other individual factors that may affect the risk are not included, such as obesity, prior history of back pain, depression, and other psychosocial variables. The reason for not including the individual factors other than age and gender in the ISO standard 11228–1 is the uncertain effect of the individual and psychosocial factors on the development of low back disorders (Hartvigsen et al., 2004; Lu et al., 2014).

The purpose of this study is to review the exposure-risk associations between the LI metrics and various low back pain outcomes and to provide the risk threshold values of the LI metrics for the protection of low back disorders in the general working population.

2. Methods

For the systematic review of the exposure-risk associations between the LI metrics and various low back health outcomes, we used peer-reviewed articles published in several bibliographic databases including Pubmed, Ergonomic Abstracts, Scopus, Google Scholar and NIOSH-TIC-2. Because many researchers did not include the term “revised” or “NIOSH” in their articles related to the RNLE, we decided to use the search string “lifting equation” or “lifting index” in the title, keyword and abstract to find all relevant articles. Because the RNLE was first announced in 1991, the search period was set from Jan 1st, 1991 to December 30th, 2018. Reference lists of identified manuscripts were also read to identify any missing studies not found in the search. Non-English documents were not included in this review.

We used the National Institute of Health (NIH)'s quality assessment tool for observational cohort and cross-sectional studies as the quality appraisal method (https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools). The appraisal criteria contain 14 items for rating the overall quality of each article. Three of the authors of the present study rated “Yes” or “No” for meeting each criterion for assessing the quality of each paper using the instructions provided by the NIH tool. The raters were blinded for the initial appraisal then met on a conference call to discuss discrepancies in the ratings. A consensus was reached to revise the ratings if deemed inaccurate. After the revision, the percentage of meeting the criteria (i.e., Yes to the questions) of each paper by each rater was calculated as one individual quality score. The rating scores were averaged across three reviewers to determine the final quality of each paper. As described in the NIH instructions, there is no consensus on the rating score threshold as a good paper. We arbitrarily chosen three *a priori* cut-off percentages of the met criteria as poor ($\leq 50\%$), fair ($50\% <$ and $\leq 75\%$) and good ($> 75\%$) quality papers.

3. Results

3.1. Results of the systematic review

A total of 115 articles published from January 1, 1991 to December 2018 were found. Of the articles, 15 epidemiological studies were identified and rated for this review. The characteristics of the studies and the average ratings are presented in Table 1. As seen in Table 1, earlier publications till 2004 were considered of lower quality (i.e., rating = poor to fair). Higher quality studies (i.e., rating = good) appeared in later years, in particular the larger scale cross-sectional studies (Waters et al., 2011; Battevi et al., 2016; Stucchi et al., 2017) and prospective studies (Lu et al., 2014; Garg et al., 2014a, 2014b; Kapellusch et al., 2014; Pandalai et al., 2016). None of the studies met the NIH quality assessment criterion “Was a sample size justification, power description, or variance and effect estimates provided?” The question “Was loss to follow-up after baseline 20% or less?” was not applicable to the cross-sectional and retrospective studies and therefore it was not included in the calculation of the quality score for these types of studies.

3.2. Determination of the LI values as risk information

In this study, various levels of the LI derivatives (i.e., LI/CLI/VLI) were reviewed and considered to be indicators of the level of exposure to the hazards which were associated with the physical demands of manual lifting jobs. The interpretation of the levels of the LI derivatives as risk information was based on the significant relationship between the LI metrics and various low back health outcomes.

Table 1 shows different levels of the LI/CLI/VLI that were assessed in the studies. To deliberate the LI values as risk information, we used the information from studies that were rated good on average. That is, the results of the study labeled numbers 6–15 in Table 1. Because in study number 6 (Xiao et al., 2004), no exposure-risk relationship was tested statistically, the study was not included for our consideration of classifying the LI values as risk information. It is worth mentioning that in the studies labeled 1–5, a positive relationship was found between the LI value > 1.0 and low back pain outcomes, such as company medical records, self-reported low back pain and low back discomfort ratings. This finding further supports our justification for an exposure-risk relationship between the LI and low back health outcomes.

3.3. Synthesis of the risk information in the epidemiological studies

It is impossible to conduct a meta-analysis of the risk information in the studies numbers 7–15 because of the different outcome measures. On average, the significant threshold value for the LI metrics was about 2.0 for different LBP outcomes across the studies. Because the two large scale studies (Battevi et al., 2016; Stucchi et al., 2017) had a sample size (N = 3,402) far greater than the remainder of the studies, we thought that their findings might bear more weight in determining the threshold value. Moreover, although we used study numbers 7–15 in Table 1 as the primary source of synthesizing risk information, earlier studies in Table 1 and other laboratory research provide some insight into the determination of the threshold value.

Waters et al. (1999) found that the increase in risk of reported low back injury was statistically significant with LIs greater than 2.0. Subsequent and expanded published research utilizing larger worker samples across various industries have used LI and CLI as the only exposure metric and have largely supported the earlier findings of an increase in LBP for LIs/CLIs over 2.0 (Waters et al., 2011; Lu et al., 2014). The Waters et al., 2011 study showed that on the basis of prevalence proportion ratios (a way to take account of the various confounding factors in a cross-sectional study) for the categories of LI ranges, the risk of low back injury in the LI/CLI ranges of 0–1 and 1 to 2 were virtually identical. This may be indicative that there is very little difference in the risk associated with a LI/CLI between 0.0 and 2.0 for a variety of lifting tasks.

While the risks associated with the range of LI and CLI have not been unequivocal, a number of studies have identified useable risk thresholds for the interpretation of the LI and CLI. In a study looking at the incidence of work-related LBP as related to the LI and CLI of jobs for 750 material handling workers, Boda et al. (2010) concluded that the LI/CLI design ideal of 1.0 would need to be increased by at least 20% to reflect the design intent of the original NIOSH publication (Waters et al., 1994). In the most comprehensive comparison to date, Potvin (2014) compared the NIOSH RWL in 216 lift conditions to the specific biomechanical, physiological and psychophysical criteria used in the development of the NIOSH equation. Potvin found that the RWL was found to be much more conservative than expected with the average RWL actually being acceptable to more than 95% of the female population across a range of moderate lift frequency. This finding was

Table 1
Epidemiological studies (in chronological order) investigating the relationship between various types of LI metrics and LBD outcomes.

No.	Authors	N	Study Design	LI Metric	Health Outcome	LI Value Threshold*	% of Met Criteria	Quality**
1	Schneider et al., (1997)	19	Retrospective	CLI	Company MSD records	Unclear	35.9	Poor
2	Wang et al., (1998)	97	Retrospective	LI	Low back discomfort rating	1.0	56.4	Fair
3	Waters et al. (1999)	308	Cross-sectional	LI	Self-reported LBP 7 days or more in the past year	2.0	64.1	Fair
4	Marras et al. (1999)	353***	Retrospective	LI	Company low back injury records in the past 6 years	3.0	61.1	Fair
5	Sesek et al., 2003	182***	Retrospective	LI	Company low back injury records related to medical visits in the past year	1.0	50	Fair
6	Xiao et al., 2004	69	Cross-sectional	LI	Self-reported LBP 7 days or more in the past year	Unclear	76.9	Good
7	Kucera et al., 2009	105	Prospective		LBP limiting normal work activity	3.0	78.2	Good
8	Waters et al. (2011)	677	Cross-sectional	LI	Self-reported LBP 7 days or more in the past year	1.0	79.9	Good
9	Lu et al. (2014)	78	Prospective	CLI	Self-reported LBP 7 days or more in the past year	2.0	83.3	Good
10	Kappellusch et al., 2014	258	Prospective	CLI/LI	Medical care due to LBP in past 90 days	3.0	81.0	Good
11	Garg et al. (2014b)	258	Prospective	CLI/LI	Sickness absence due to LBP in past 90 days	2.2	83.3	Good
12	Garg et al. (2014a)	258	Prospective	CLI/LI	LBP > 1 day in past 90 days	3.0	81.0	Good
13	Pandalai et al. (2016)	138	Prospective	CLI	Self-reported LBP 7 days or more in the past year	1.5	80.2	Good
14	Battevi et al. (2016)	3,402	Cross-sectional	VLI	Acute LBP in the past year	1.0	78.0	Good
15	Stucchi et al., 2017	3,402	Cross-sectional	VLI	Acute LBP in the past year	1.0	75.1	Good

* Value that is significantly associated with an increased risk of the LBP outcome.
** Quality assessment is based on the averaged percentage of the met criteria in the NIH quality assessment tool: Poor (< 50%); Fair (50–75%); Good (76–100%).
*** The number is for jobs instead of persons.

consistent with earlier research. Potvin concluded that on average the RWL would have to be multiplied by 1.68 (a 68% increase) in order to produce a value that reflects the biomechanical, physiological and psychophysical design criteria overall defined by the original NIOSH publication (Waters et al., 1994). Taken together, this suggests that a useable risk threshold between low and intermediate or high risk of LBP would fall somewhere intermediate between CLI of 1.0 and 2.0. This suggestion is in agreement with the main finding in a recent prospective study (Pandalai et al., 2016) using a Bayesian random threshold approach to estimate the probability of an increase in LBP in 138 manufacturing workers. A threshold value for CLI of > 1.5 was found to be associated with the risk of LBP in Pandalai et al.'s study.

Because Battevi et al.'s study is by far the largest field study ever conducted to examine the relationship between one of the LI metrics (i.e., VLI) and LBP, it deserves additional attention to their research findings. In Battevi et al.'s study, a sample of 3,402 study participants from 16 companies in different industrial sectors was analysed. Of the participants, 2,374 were in the risk exposure group involving manual lifting, and 1,028 were in the reference group without manual lifting. The VLI was calculated for each participant in the exposure group. Occupational physicians at the study sites collected LBP information. In particular a subject was assessed as positive if she/he reported at least one episode of acute LBP in the last year (12 months).

The risk of acute LBP was estimated by calculating the odds ratio (OR) between levels of the risk exposure (i.e., levels of VLI) and the reference group using a logistic regression analysis. In addition to crude ORs, the ORs of the VLI for acute LBP were further adjusted for body mass index, gender, and age.

Both crude and adjusted ORs showed an exposure-risk relationship. As the levels of LI increased, the risk of acute LBP increased. This risk relationship existed when LI was greater than 1. The adjusted ORs suggested that workers with $1 < \text{VLI} \le 2$ and $2 < \text{VLI} \le 3$ had a 76% and a 200% increased risk of acute LBP, respectively. When VLI values exceeded 3, the OR had a little decline with respect to the $2 > \text{LI} \ge 3$ class but was still high (OR = 2.23) and statistically significant, as compared with the reference group. The slight decline in the ORs in the class of LI > 3 was likely due to the survivor effect.

These results confirm that, considering the health effect "Acute LBP", a LI of 1 is a good discriminatory point between a still acceptable and a risky condition across all frequencies of lifting: This is however particularly true for lifting high loads at frequencies of lift that are < 0.1 (lower than one lift per 10 min, the definition in ISO 11228–1 of repetitive lifting).

It should be noted that the potential survivor effect in Battevi et al.'s study was also observed in four previous large scale epidemiological studies (Waters et al., 1999, 2011; Seidler et al., 2009; Lu et al., 2014; Garg et al., 2014a, b; Lu et al., 2016). In deliberating the risk interpretation of the LI metrics, the authors thought that the slight decline in the ORs in the previous studies did not warrant an attenuation in the risk level for LI > 3.0.

3.4. *A suggested interpretation strategy of the LI values*

Generally, the LI should be used as an indicator of the level of exposure to overall physical demands for repetitive manual lifting activities. Based on the above synthesized information on the association between the LI metrics and low back health outcomes, the risk information associated with different levels of the LI and recommended actions are presented in Table 2. The information in Table 2 is also used in Annex H of the draft of the revised ISO 11228–1 (ISO, 2018).

We have considered an LI of 1.0 as a prudential threshold, and indeed as a traditional design limit, for protecting most workers from low back pain although the "true" cut off value of the LI for protecting most workers from low back disorders is most likely to occur in the range between 1 and 2. An increase in the LI above 1.5 is suggested to be a moderate risk indicator for low back disorders. A LI value above 2.0 and 3.0 is considered high and very high risks, respectively: in these cases, changes to the task to reduce the LI value to minimize risk levels should be a high priority.

4. Discussion

The RNLE and its extensions (i.e., derived lifting index metrics) are certainly useful tools in the evaluation of lifting and lowering tasks. As noted, the RNLE is the most frequently used ergonomics assessment tool among professional ergonomists in four English Speaking countries (US, Canada, UK and Australia), which is indicative of how ubiquitous lifting tasks are across industry and services (Lowe et al., 2018). However, written or documented guidance for users on interpreting the results of the RNLE has not necessarily been detailed or comprehensive. A number of the publications by the equation's authors (e.g., Waters et al., 1993; Waters et al., 1994, Waters and Piacitelli, 1997; Waters et al.,

Table 2
Interpretation of Lifting Index and derivates (*LI, CLI, VLI, SLI*).

Lifting Index Value (Exposure level)	Risk Implication	Recommended Actions
LI ≤ 1,0	Very low	None in general for the healthy working population.
1,0 < LI ≤ 1,5	Low	In particular pay attention to low frequency/high load conditions and to extreme or static postures. Include all factors in redesigning tasks or workstations and consider efforts to lower the LI to values ≤ 1,0.
1,5 < LI ≤ 2,0	Moderate	Redesign tasks and workplaces according to priorities to reduce the LI, followed by analysis of results to confirm effectiveness.
2,0 < LI ≤ 3,0	High	Changes to the task to reduce the LI should be a high priority.
LI > 3,0	Very high	Changes to the task to reduce the LI should be made immediately.
For Any level of Risk/Exposure	Identify any workers who may have special needs or vulnerabilities in lifting tasks and assign or design the work accordingly. Training workers on recognizing and eliminating material handling hazards is regarded as beneficial. Limiting the weight to be lifted, to less than the Reference Mass may also be considered.	

2011) noted that the risk of lifting-related LBP would likely increase with an LI > 1.0 (based upon the biomechanical, physiological and psychophysical criteria used in developing the equation) but also noted that the shape of the risk function was not known. The body of epidemiological studies reviewed in this paper allow a more detailed and nuanced interpretation of the RNLE based upon a better understanding of risk of back injury.

As a result of the many different individual factors amongst people, the same exposure to a hazard (e.g. manual lifting) for different people does not necessarily present the same degree of risk. The suggested risk information in Table 2 may be used for the general healthy working population. Practitioners should exercise caution in interpreting the risk information when designing manual lifting jobs for aging, female or return-to-work workers from prior musculoskeletal injuries.

The extensions of the RNLE mentioned in this article (CLI, SLI, VLI, CULI) should be considered by users as appropriate for the lifting tasks being assessed. Furthermore, the RNLE and its extensions need not necessarily be the exclusive tool used by the ergonomics analyst in assessing lifting tasks as it does not assess all potential risks of lifting tasks. Depending upon task specifics, the user may want to supplement the lifting analysis with additional analyses for low back loading. For example, the analyst could use biomechanical analysis tools such as the University of Michigan 3D SSPP® (Chaffin et al., 2006) or the 3D dynamic simulation tool "The Dortmunder" (Jäger et al., 2001) in combination with the age-related gendered "Revised Dortmund Recommendations" (Jäger, 2018) to assess the compressive spinal loading due to high-force application or disadvantageous postures of the spine to supplement the RNLE. Given that the RNLE is partly based upon static loading, it is unable to assess highly dynamic lifting motions or spinal motion (Marras et al., 1995). The Lumbar Motion Monitor or LMM (Marras et al., 1993, 1995) can be a useful tool to assess highly dynamic lifting and torso movement. In the case where lifting tasks involve walking, carrying and other handling tasks, oxygen consumption, heart rate, and prediction of energy expenditure could be employed to assess the overall metabolic demands of the work (Waters et al., 1998; Garg et al., 2004).

There are other approaches as well that can be used to assess different aspects of lifting, carrying, pushing/pulling and other handling tasks. Applying the so-called Dortmund Approach, the determination of the biomechanically induced low-back load and its assessment related to short-term as well as long-lasting occupational activities can be achieved (Jäger and Luttmann, 2005). Compressive forces aggregated via cumulative dose models during the total occupational lifetime, can be assessed with respect to the development of lumbar spine degenerative diseases applying epidemiologically derived dose thresholds in the "Mainz-Dortmund Dose Model", which represents the common method in worker's compensation occupational disease assessment procedures in Germany (HVBG, 2003). The German Spine Study EPILIFT and EPILIFT2 (Bolm-Audorff et al., 2007; Seidler et al., 2009, 2014), examined the health-effects in relation to lumbar-disc herniation ("prolapse") and lumbar disc-space narrowing ("chondrosis") accompanied by functional deficits i.e. sensitive and/or motor radix syndrome or local syndrome of manual material handling tasks and disadvantageous postures. The results suggest potentially different etiologic pathways between the development of the mentioned degenerative diseases and low-back pain, as a nested study regarding the 12-month prevalence of low-back complaints have shown (Bergmann et al., 2017). Follow-on studies (Jäger et al., 2011; Seidler et al., 2014) developed cumulative lumbar-load dose models which did a best-fit of the dose-risk associations, and identified thresholds serving as "best estimates" to address questions related to a "heavy" object weight, a "disadvantageous" working posture and "critical" lifetime doses based upon daily exposure and included push and pull activities.

Gallagher et al. (2017) presented a tool also based upon considerations of cumulative loading and fatigue failure theory. Such data or methods may be difficult to directly compare with the RNLE as the RNLE does not take into account cumulative loading or the inclusion of combined tasks. However, these tools and methods can be used to supplement or extend a NIOSH analysis and give the user additional information to make decisions on the risks of the lifting task. Additionally, psychosocial factors have been identified as well as having a role in the onset of low-back pain that should be considered by practitioners (e.g., Yang et al., 2016).

Battevi et al. (2016) suggested that more infrequent lifting (lifting less frequent than 1 lift per 10 min) appears to be more hazardous than frequent lifting (in determining acute low back pain). This finding might indicate that the less practiced a worker is at a lifting task is, the more hazard that it might present to that lifter. As such the analyst might want to take precautions with less-frequent lifting tasks.

When interpreting the LI of a lifting or lowering task, the analyst may also want to inspect the particular multipliers of the task to see which have the most impact on the LI. Also, a number of users of a similar interpretation strategy to that in Table 1 have taken the extra step of setting a mass limit for the containers or objects lifted that takes into account the particular parameters of the tasks in addition to the use of the RNLE as part of their guidelines (AIAG, 2006; SAE/USCAR, 2015). The RNLE in these cases is used primarily to assess conditions of aggregate lifting. As far as worker training in proper manual handling methods (e.g., "lift with the legs and not with the back"), we note that reliance on worker training has not been supported by quality intervention studies for preventing LBP according to multifactorial genesis of musculoskeletal pain (Verbeek et al., 2012). However, worker training in recognizing MMH hazards in the workplace and the opportunity to work with management to reduce or eliminate them can complement sound ergonomic workplace and task design and other engineering and organizational interventions (van der Beek et al., 2017).

5. Conclusion

The interpretation strategy for different levels of the LI presented in this paper is intended to help the user better apply the RNLE and to better set priorities in the addressing of lifting tasks. Given that the RNLE is the most frequently used ergonomics assessment tool, it can be speculated that decisions made on the basis of the metrics of the RNLE drive considerable labor and workplace engineering costs for industry (material presentation equipment, material handling assists, etc.). As such it can be strongly suggested that a consistent strategy based upon research be used to interpret the output of the RNLE (e.g., LI, CLI, SLI, VLI, CULI). The user should understand the difference between "exposure" and "risk" and should keep in mind the use of other assessment tools to supplement the RNLE if needed. In all, a holistic approach utilizing a suite of tools and methods to assess lifting tasks is recommended.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apergo.2019.102897.

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