Proceedings of the 5th Annual World Conference
of the Society for Industrial and Systems Engineering,
San Francisco, CA, USA
October 13-14, 2016

Using the Revised NIOSH Lifting Equation in the Mexican Workplace: Biomechanical, Physiological, and Psychophysical Differences

M. Christian[1], J.E. Fernandez[1], G. Ibarra-Mejía[2] and R.J. Marley[3]

[1]JFAssociates, Inc.
Vienna, Virginia 22181, USA

[2]University of Texas at El Paso
Department of Public Health Sciences
El Paso, Texas 79968, USA

[2]Universidad Autonoma de Ciudad Juarez
Department of Industrial Engineering
32310 Cd Juárez, Chih., Mexico

[3]Missouri University of Science and Technology
Office of the Provost, 210 Parker Hall
Rolla, Missouri 65409, USA

Corresponding author's Email: jf@jfa-inc.com

Author Note: Dr. Marc Christian obtained his PhD from Virginia Tech in 2014 and is currently the Managing Engineer at JFAssociates, Inc. and also serves as the Newsletter Editor for the International Society for Occupational Ergonomics and Safety. His expertise and research includes occupational ergonomics, workplace injuries, and biomarkers related to tissue injury.

Dr. Jeffrey Fernandez is the managing principal at JFAssociates, Inc. and is currently the president of the Board of Certified Professional Ergonomists (BCPE). He previously was a professor at Wichita State University, a Senior Research Associate at NIOSH, and is currently an adjust professor at George Mason University. Dr. Fernandez is internationally known for his research in occupational ergonomics and industrial engineering.

Dr. Gabriel Ibarra-Mejía MD PhD is an assistant professor at the University of Texas at El Paso's Department of Public Health Sciences, adjunct professor at the University of Texas Health Science Center at Houston, and at the Universidad Autonoma de Ciudad Juarez's Department of Industrial Engineering. His areas of expertise are in environmental, occupational health and industrial ergonomics focusing on the work design for the prevention of work-related musculoskeletal disorders.

Dr. Robert Marley is the Provost and Executive Vice Chancellor of the Missouri University of Science and Technology in Rolla, Missouri. He is also a Professor in the Department of Engineering Management and Systems Engineering, and maintains research and teaching interests in human factors, occupational ergonomics and safety engineering. He is a Board Certified Professional Ergonomist (CPE).

Abstract: The Revised NIOSH lifting equation (RNLE) is designed to approximate the relative risk of developing low-back injuries for two-handed, stationary, lifting tasks. Biomechanical, physiological, and psychophysical studies of the US population were used when determining appropriate RNLE threshold values in order to minimize the risk of low-back injuries. Despite being designed for the US population, the RNLE has gained international popularity primarily due to its ease of application and studies demonstrating successful reductions in low-back injuries in the US. Since only task-related factors determine the risk, the RNLE inherently assumes the same biomechanical, physiological, and psychophysical criteria for all people.

A number of studies have demonstrated that Mexican and Hispanic American populations generally have lower threshold values for the biomechanical, physiological, and psychophysical criteria which are assumed constant in the RNLE. It is well documented that Mexican populations typically have smaller anthropometric measures, and that Hispanic Americans are less tolerant to pain and discomfort than those in the US. Such differences suggest that the RNLE may underestimate low-back injury risk when applied in a Mexican workplace and that modifications to the measured RNLE factors are needed to accurately estimate risk.

Keywords: NIOSH Lifting Equation, Mexico, Anthropometry

1. Introduction

The Revised NIOSH Lifting Equation (RNLE) was proposed in 1991 as a tool for assessing the relative 'risk' for low-back injury for two-handed, stationary, lifting tasks. Seven, task-specific, factors were chosen to modulate a load constant, set at 51lbs (23kg). Then, one compares the actual load to that of the modified load constant to determine a lifting index (LI). As the actual load exceeds the load constant, the LI indicates a higher risk of low-back injury. Such tasks should be modified or redesigned to reduce the impact that the task-specific factors have on the load constant.

In order to eliminate the need for measurements of the individual performing the task, the task-specific factors which modulate the load constant were designed based on previous studies of human biomechanics, physiology, and psychophysics. A panel of experts convened to judge the current scientific evidence regarding the likelihood of low-back injuries and develop a rationale for weighting each task-specific factor.

After reviewing the available evidence, the panel agreed on three upper limits to form the basis of the RNLE. This three factors are detailed in Table 1.

Table 1. Criteria used to develop the lifting equations (Waters, Putz-Anderson, Garg, & Lawrence, 1993).

Discipline	**Design Criterion**	**Cut-off value**
Biomechanical	Maximum disc compression force	3.4 kN (770lbs)
Physiological	Maximum energy expenditure	2.2-4.7 kcal/min
Psychophysical	Maximum acceptable weight	Acceptable to 75% of female workers and about 99% of male workers

The criteria shown in Table 1 were then translated into the equations which modulate the load constant. These formulas are summarized in Table 2.

Table 2. RNLE multipliers (NIOSH, 1994).

Multiplier	**Formula (distances in inches)**	**Optimal**
Load Constant	51 lb	-
Horizontal Multiplier	10 / H	H ≤ 10
Vertical Multiplier	1 - (0.0075 x |V - 30|)	V = 30
Distance Multiplier	0.82 + (1.8 / D)	D ≤ 10
Asymmetric Multiplier	1 - (0.0032 x A)	A = 0
Frequency Multiplier	Based on frequency (lifts/min) and work duration (up to 8hrs)	Frequency ≤ 0.2/min Duration ≤ 1hr
Coupling Multiplier	Based on descriptions of 'good', 'fair', and 'poor' handles	Having handles or hand can easily be wrapped around the object

It is important to note that each of these multipliers only decreases the load constant, which means that the multipliers can only optimally be 1.0, e.g. even if the H for the horizontal multiplier is less than 10, the value is taken as 1.0. Based on this knowledge, the optimal values of the lift factors are shown in Table 2.

The ease of application and simplicity of the task factors makes the RNLE a powerful and versatile tool for workplace design considerations. Results regarding the efficacy for predicting injury have shown a mix between positive and mixed results (Garg et al., 2013; Lu, Waters, Krieg, & Werren, 2014; Waters, Lu, Piacitelli, Werren, & Deddens, 2011). It is important to note though that these studies use a standard US population, which is what the RNLE was designed to accommodate.

Anecdotal data by the authors indicates that a direct application of the RNLE in a Mexican population does not yield the same protective effects as it does in the US. In other words, we hypothesize that when the same LI cut-off criteria is used the rate of injury is higher in a Mexican population than it is in the US. This type of inaccurate risk estimation suggests that there is an issue with the underlying model assumptions. Unfortunately, there is a paucity of scientific evidence studying the efficacy of the RNLE in non-US populations.

2. Differences Between US and Mexican Workers

As discussed above, the optimal values for the multipliers are based on previously established data. However, such data is limited, and is almost always based on studies performed in the US with a US population. For example, the optimal vertical distance multiplier is at 30 inches, which is the same as the standing knuckle height for a US male (Fernandez & Marley, 2013). From a biomechanical perspective this makes sense, since a lift occurring at knuckle height does not require any back flexion, thus minimizing risk.

There are known differences in the biomechanical, physiological, and psychophysical capabilities between US and Mexican populations. It stands to reason that such difference would contribute to the observed discrepancies between predicted and observed low-back injuries when applying the RNLE in a Mexican population.

Several common anthropometric measures in a Mexican population are typically smaller in dimension than those of a US population. Table 3 shows the average values for stature, shoulder height, and knuckle height between US and Mexican people. As one can see, for the same gender, measures obtained for a Mexican population are all less than those of US people. Differences range from 0.6 (shoulder-grip length, female) to 3.2 inches (stature, male).

Table 3. Select mean anthropometric measures (in inches) of a US and Mexican population (Fernandez & Marley, 2013; Fernandez, Marley, Noriega-Morales, & Ibarra-Mejía, 2008; Ibarra-Mejía et al., 2010).

Measure (inches)	**US**		**Mexico**		**Differences (US - Mexico)**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**
Stature	69.1	63.9	65.9	61.7	3.2	2.2
Shoulder Height	56.7	52.2	54.3	50.8	2.4	1.4
Knuckle Height	30.1	28.7	29.1	27.8	1.0	0.9
Shoulder-Grip Length	26.4	24.0	25.4	23.4	1.0	0.6

In terms of physiological measures, there is less evidence demonstrating a difference between a US and Mexican population. The RNLE was based upon the maximum energy expenditure, in kcal/min. This value is typically inferred by determining maximum rate of oxygen consumption, as VO_{2max}. The committee which selected the RNLE criteria suggested that 9.5kcal/min was the average lifting capacity for a 50th percentile 40-year old female worker (Waters et al., 1993). A more recent study by Schiller, Casas, Desouza, and Seals (2001), suggests that Caucasian 40-49-year old females have a VO_{2max} of about 9kcal/min, while the Hispanic population has a value of 8.5kcal/min. It should be noted that Hispanic females are not necessarily representative of Mexican females, however, the decrement in capacity is notable. Unfortunately, similar differences have yet to be demonstrated between a male US and Mexican population.

Further, some physiological differences are commonly related to anthropometric measures. As discussed above, the anthropometric measures for a Mexican population are lower, in every measure, in comparison to the US. Therefore, when performing the same task, e.g. same mass, distance, heights, etc., those with different anthropometric measures should have an altered physiological capacity. While the scientific studies are lacking to support this assertion, it is consistent with basic biomechanics calculations.

Finally, we consider the psychophysical differences between US and Mexican populations. The RNLE is based on the criteria that a lifting task should be acceptable to 75% of females. Scientific evidence had suggested that, when a lifting task is acceptable the less than 75% of the female population, the risk of low back injury increases by three-fold (Waters et al., 1993). There is scientific and anecdotal evidence to suggest that Mexican populations have a lower psychophysical capacity than US population. Pinch grip strength has specifically been shown to be significantly lower in Mexican than US populations. Table 4 illustrates such differences in pinch strengths. It is important to note that the pinch grip strengths for Mexican populations is often less than half of the values seen for the US.

Table 4. Select pinch grip strengths (in kg) of US and Mexican populations (Ibarra-Mejía et al., 2013).

Gender	Hand	Pinch Type	US	Mexico	Difference (US - Mexico)
Male	Right	Tip	8.2	4.0	4.2
		Lateral (key)	11.8	6.9	4.9
		Palmar (chuck)	12.1	4.5	7.6
	Left	Tip	7.7	2.6	5.1
		Lateral (key)	11.3	6.3	5.0
		Palmar (chuck)	12.6	5.1	7.5
Female	Right	Tip	5.0	1.2	3.8
		Lateral (key)	8.0	3.8	4.2
		Palmar (chuck)	7.8	2.6	5.2
	Left	Tip	4.8	1.0	3.8
		Lateral (key)	7.4	3.5	3.9
		Palmar (chuck)	7.4	3.1	4.3

Another measure of psychophysical capability includes the sensitivity to pain, as this would tend to predict the ability to perform sustained work. It has been shown that individuals of Hispanic ethnicity tend to have a higher sensitivity to pain in comparison to Caucasians (Rahim-Williams et al., 2007). This suggests that Hispanic populations, when performing the same type of lifting task, would tend to report a lower psychophysical capability, as perceived pain and discomfort are often a factor in determining psychophysical capabilities (along with fatigue and other variables). As above, it should be noted that Hispanic populations do not necessarily represent Mexicans, however such data in Mexicans is not available.

Ideally, there would be data which directly compares the psychophysical capability directly between US and Mexican populations, using a standardized protocol. While this data has not been published in a scientific journal, two of the authors (Fernandez and Ibarra-Mejía) have performed this research at the Universidad Autónoma De Ciudad Juárez using a male population. Results here suggested that the Mexican populations had approximately 65% of the lifting capacity of US population.

The purpose of this discussion has been to highlight the presence of substantial differences between US and Mexican populations. Of specific interest here were differences in the biomechanical, physiological, and psychophysical capabilities, since these are assumed to be standard when using the RNLE. Such differences would likely influence the underlying assumptions, and would account for the observed differences when applying the RNLE in a Mexican population.

3. Implications of Biomechanical, Physiological, and Psychophysical Differences for RNLE Multipliers

Until this point we have argued that differences in biomechanical, physiological, and psychophysical parameters between the US and the Mexican working population. A vast amount of research is still required to determine the precise impact that the known differences on the RNLE multipliers (Table 2). However, we can hypothesize the likely direction of change which the RNLE multipliers will need to take in order to accommodate the already known differences.

The load constant itself is a critical assumption of the RNLE, which assumes that, under otherwise ideal conditions, a worker can be expected to lift 51lbs. The physiological maximum capacity 8.5 vs. 9.5 kcal/min is 89.5% and the unpublished data by the authors maximum lifting capacity (see above) suggests the psychophysical capacity is 65% in Mexicans vs US people. This would suggest that the load constant of the RNLE should be decreased to be between 33 to 46lbs. Such a decrease would have a substantial impact on the calculated LI.

The horizontal, vertical, and distance multipliers would also be impacted by the known biomechanical differences. For example, the optimal height for the vertical multiplier is 30 inches, because the standing knuckle height for a US male is ~30 inches. By performing a lift at the standing knuckle height a person would not be required to engage in back flexion, nor utilize arms muscles to hold or lift the item. Since, the standing knuckle height for Mexican males is ~29 inches though, the optimal vertical height for a lift should be 29 inches, otherwise the RNLE would produce an inaccurate estimate. Similarly, the upper limit for lifting is 70 inches, since this is the mean US male stature. In a Mexican population this limit should be decreased to 66 inches, their mean stature. One could continue in a similar fashion for the distance and horizontal multipliers, since the shoulder grip lengths are shorter for the Mexican population, however extrapolating those differences based on the current data is beyond the scope of this paper.

The thresholds for the frequency multiplier would likely also decrease when incorporating the physiological and psychophysical differences noted above. Again, assuming the capacity in Mexican populations is between 65 and 89% of US people, we can change the multiplier values to 65 and 89% of their previous values. It is important to note then, that even the optimal values of ≤0.2lifts/min and ≤1hr of lifting duration, the frequency multiplier only starts at 0.65 and 0.89 respectively, where previously it would have been 1.0.

Finally, there are the coupling and asymmetry multipliers. Based on the significant decrease in grip strengths presented in Table 4 we can assume the coupling multiplier would be altered, but due to the subjective nature of the descriptions of the coupling multiplier we cannot quantify the possible differences. As for the asymmetry multiplier we have no data to suggest differences between US and Mexican populations.

4. A Worked Example

To demonstrate the effect of the proposed changes to the RNLE multipliers on an example task we will provide a worked example for a lifting task. Figure 1 gives an overview of the lifting task to be analyzed with the RNLE. Note that the frequency is 3 lifts/min and duration is 45 minutes. Table 5 states the RNLE multipliers and calculates the LI for the original values and for the proposed values using both the 65% and 89% proposed cutoffs as well as the 29-inch standing knuckle height. It is important to note that this example is only illustrative and not intended to propose actual future values for the RNLE multipliers. Significantly more research is needed to determine the precise impact the above discussed differences would have.

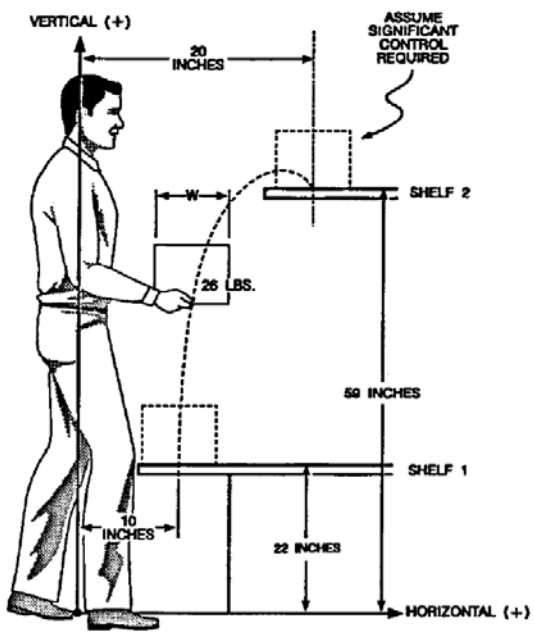

Figure 1. Dimensions of a package inspection task (NIOSH, 1994).

Table 5. Lift index calculation for the original, and 65% and 89% cutoff modifications. Different multipliers are indicated in bold and maximal LI values for each scenario are highlighted using the typical red, yellow, green limits.

	Original		**65%**		**89%**	
	Origin	**Destination**	**Origin**	**Destination**	**Origin**	**Destination**
Load Constant	51	51	**33**	**33**	**46**	**46**
Horizontal Multiplier	1	0.50	1	0.50	1	0.50
Vertical Multiplier	0.94	0.78	**0.95**	0.78	**0.95**	0.78
Distance Multiplier	0.87	0.87	0.87	0.87	0.87	0.87
Asymmetry Multiplier	1.0	1.0	1.0	1.0	1.0	1.0
Frequency Multiplier	0.88	0.88	**0.57**	**0.57**	**0.78**	**0.78**
Coupling Multiplier	0.95	1.0	0.95	1.0	0.95	1.0
Recommended Weight Limit	34.9	15.2	14.8	6.4	28.2	12.2
Object Weight			26			
Lift Index	0.8	1.7	1.8	4.1	0.9	2.1

The calculations in Table 5 demonstrate the expected changes in final LI when accounting for some of the known differences between US and Mexican populations. In either case, implementing any of the proposed changes results in an increase of the LI, indicating greater inury of risk. The range for the modified LIs are 2.1 to 4.1. This is a very wide range, where the upper limit of 4.1 would imply lift is a 'high risk' task, while the lower limit of 2.1 has only a marginally higher risk than the original, and is still classified as a 'medium risk' task. In reality, an LI of 4.1 is likely an overestimate, while 2.1 is an underestimate, and the true value is somewhere within this range. Clearly, more research is needed in order to refine the estimates obtained here.

5. Conclusions

Practitioner data suggests that the RNLE underpredicts low back inury risk in Mexican populations. The purpose of this paper was to document the types of biomechanical, physiological, and psychophysical differences known to exist between US and Mexican populations. When being applied in a Mexican population, differences in such variables would influence the RNLE multipliers,. In almost all cases we observe smaller anthropometric measures, and lower capacities and tolerances in Mexican populations. These changes suggest a lower recommended weight limit, and therefore higher lifting index, when lifting the same weight. A worked example of a lifting task demonstrated a marked increase in LI. This suggests the current RNLE underestimates low back injury risk in Mexican populations. More research is needed in order to quantify all differences between US and Mexican populations relevant to the RNLE, and then develop modified RNLE multipliers applicable to the Mexican population.

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