The NIOSH Lifting Equation for Manual Lifting: A Literature Review

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Abstract- The literature on the problems caused by frequent lifting and lowering tasks has grown rapidly in the past few decades. This paper focuses on presenting literature on the NIOSH Lifting Equation, which is used for calculating injure-free lifting capabilities for workers who perform two-handed manual lifting tasks. The papers acquired for the study focus on the importance of the equation to reduce the effect of Low Back Pain (LBP) associated with various lifting operations. The result of the study is a systematic research and compilation of various aspects of the equation and its applications at construction sites and industrial organizations and in future will be applied at a manufacturing firm to know the effectiveness of lifting operations in order to ensure safe working practices for workers. The final assessment of the study is that for successful outcomes for reduction in Work related Muskuloskeletal Disorders (WMSDs) and LBP, the equation should be thoroughly considered for manual lifting practices.

Keywords – Low Back Pain, manual lifting, NIOSH Lifting Equation, Work related Muskoloskeletal Disorders

I. INTRODUCTION

The National Institute of Occupational Safety and Health (NIOSH) felt the need for the development of a technique to mitigate the effects of Low Back Pain (LBP) and Work related Muskuloskeletal Disorders (WMSDs) associated with lifting and lowering tasks, [Temple and Adams (2000), Choi et al. (2012), Waters et al. (1999), Waters et al. (1993), Elfeituri and Taboun (2002)]. It published the Work Practices Guide for Manual Lifting. The WPG included a summary of literature regarding lifting operations before 1981, (Waters, 2007). The NIOSH lifting equation was first developed in 1981 and was called the standard NIOSH lifting equation, the equation was then reformed in 1991 and was called the revised NIOSH lifting equation, (Temple and Adams, 2000). The revised NIOSH lifting equation included aspects such as asymmetry, coupling, frequency etc. for manual lifting, (Weames et al. 1994). These parameters proved to be of greater importance and more training is required for their use, (Dempsey, 2002). The equation was designed to provide a limit beyond which there would be a need to take ergonomic measures to curtail the risks, (Waters et al. 1993. Back injuries prevail as most common and costly in agriculture too i.e. California agriculture has an average of 3,350 back injuries each year which accounts for more than $30 million, (Meyers et al. 2006). The lifting equation is applicable to two-handed lifting tasks. One- and two-handed repetitive lifting tasks form a part of many occupations. Thus the metabolic demands of one- and two-handed tasks should be clearly understood to know if they would provide similar outcomes because a job design which would take this into consideration would prevent injuries related to lifting tasks, (Sevene et al. 2012).). A study indicated that approximately 650,000 workers every year suffer injuries and illnesses caused by overexertion, repetition etc. which have caused the US businesses to incur compensations between $15 to $20 billion dollars a year, (Temple and Adams, 2000).

II. LITERATURE SURVEY

A. About the Equation-

Calculations to be carried out to find outcomes of equation:

The revised NIOSH lifting equation (1991) is used to evaluate the manual lifting tasks, [Temple and Adams (2000), Choi et al. (2012), Waters et al. (1999)]. The primary outcome of the lifting equation is the RWL which gives the limit of the maximum weight that all healthy workers can lift. Once the RWL is determined the Lifting index (LI) is calculated from it. The value of the LI suggests the level of stress that will be associated with the specified lifting task being evaluated, (Waters et al. 1999). The equation is as follows, [Choi et al. (2012), Waters et al. (1994)]:

RWL = LC (51 lbs) x HM x VM x DM x AM x FM x CM
LI = Weight / RWL

Details of Variables, Multipliers used in the equation:

Waters et al. (1993) explained the multipliers and the derivations of the equations which would use the respective variables to determine the multipliers. Godwin et al. (2013), explained the variables with which the multipliers can be calculated. All of these have been specified in table 1.

Table 1: Details of Variables used in the equation

Variables	Description	Multiplier	Value in Centimeters	Value in Inches
H	Horizontal location of the object relative to the body	Horizontal Multiplier (HM)	HM=(25/H)	HM=(10/H)
V	Vertical location of the object relative to the floor	Vertical Multiplier (VM)	VM=(1–0.003|V-75|)	VM=(1–0.0075|V-30|)
D	Distance the object is moved vertically	Distance Multiplier (DM)	DM=(0.82+(4.5/D))	DM=(0.82+(1.8/D))
A	Asymmetry angle	Asymmetric Multiplier (AM)	AM=(1-(0.0032A))	
F	Frequency and duration of lifting activity	Frequency Multiplier (FM)		
C	Coupling or quality of the workers grip on the object(good, fair, poor)	Coupling Multiplier (CM)		

Interpretation of outcomes of the equation:

If the LI is less than 1.0, there are nominal or no chances of LBP or WMSDs to the working healthy employees. However, if the LI is greater than 1.0, there is an increased risk of such injuries, (Godwin et al. 2013). As explained by Waters et al. (1993), the Load Constant is taken to be 51 lbs. This is considered to be the maximum recommended weight of the load that can be lifted by employees under ideal conditions. The frequency multipliers required for the equation can be determined from the values given in table 2, (Waters et al. 1993).

Table 2: Values for Frequency Multiplier, (Source: Waters et al. 1993)

Frequency (lifts/min)	Work Duration					
	<= 1h		<= 2h		<= 8h	
	V< 75	V>= 75	V< 75	V >= 75	V < 75	V >= 75
0.2	1.00	1.00	0.95	0.95	0.85	0.85
0.5	0.97	0.97	0.92	0.92	0.81	0.81
1	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.72	0.45	0.45
5	0.80	0.80	0.60	0.60	0.35	0.35
6	0.75	0.75	0.50	0.50	0.27	0.27
7	0.70	0.70	0.42	0.42	0.22	0.22
8	0.60	0.60	0.35	0.35	0.18	0.18
9	0.52	0.52	0.30	0.30	0.00	0.15

10	0.45	0.45	0.26	0.26	0.00	0.13
11	0.41	0.41	0.00	0.23	0.00	0.00
12	0.37	0.34	0.00	0.00	0.00	0.00
13	0.00	0.31	0.00	0.00	0.00	0.00
14	0.00	0.28	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00

Use of NIOSH Equation for one- and two- handed lifting tasks:

Sevene et al. (2012) compared the psychophysical and physiological work stress for identical lifting tasks which could be performed with either one or two hands. The result of the study is in table 3 which shows no significant difference in terms of physiological and psychophysical stress, when good coupling exists.

Table 3: Metabolic parameters with respect to lifting conditions, (Source: Sevene et al. 2012)

Metabolic Parameters	Lifting conditions		
	Dominant Hand	Non-Dominant Hand	Both Hands
O2 Consumption (ml/kg/min)	14.3	14.4	15.7
Liters of O2/min	1.0	1.0	1.1
kCal/min	5.1	5.1	5.6
Heart Rate	103.4	105.4	107.1
RPE (Rating of Perceived Exertion)	9.4	10.0	9.4

B. Criteria for Defining the Equation-

Three criteria were used for defining the equations (both standard and revised equations, [Potvin (2014), Waters et al. (1993)], namely:

1. Biomechanical
2. Psychophysical
3. Physiological

Reasons for selection of the three criteria:

These were selected because these factors affected the lifting operations majorly. Based on these criteria the various equations for knowing the multipliers were derived. Using these multipliers the Recommended Weight Limit (RWL) could be determined. Thus, the major use of these criteria was to know the RWL. RWL defines a limit for the weight that all healthy workers can lift while performing a lifting operation, [Potvin (2014), Waters et al. (1993)]. A study indicated that the revised NIOSH lifting equation describes the specific values used to establish a Recommended Weight Limit (RWL) and these were based on the three criteria, (Waters et al. 1993).

The three disciplines with their cut-off values and design criteria are presented in a tabular form in table 4.

Table 4: Criteria used to develop the lifting equation, (Source: Waters et al. 1993)

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

Reason for using a combination of the three criteria:

The biomechanical criteria should maintain L5/S1 compression below 3400N.The base of the spine is made up of the intricate L5/S1 vertebral segment, [Weames et al. (1994), Waters et al. (1993)]. The idea of using a combination of the three disciplines was to minimize the risks that tasks related to lifting can cause as either one of the three considered one at a time or even a combination of two would not mitigate the effects to an extent that would be protective of workers, [Potvin (2014), Waters et al. (1993)]. Also these three criteria contradict one another to an extent, for example: metabolic data suggest is more efficient to lift heavier weights less frequently than to lift lighter weights more frequently; however, biomechanical studies suggest the load should be minimized by lifting lighter weights more frequently to reduce muscle and vertebral stresses. Also, when lifting from the floor, results from psychophysical studies suggest that workers can lift loads that are heavier than those estimated from biomechanical or physiological studies, (Waters et al. 1993). Thus, a combination of the three criteria is to be used, (Waters, 2007). Potvin (2014) gave a graphical representation of the combination of the three criteria and how the RWL and Composite Acceptable Load (CAL) are determined based on it is shown below in figure 1, (Source: Potvin, 2014).

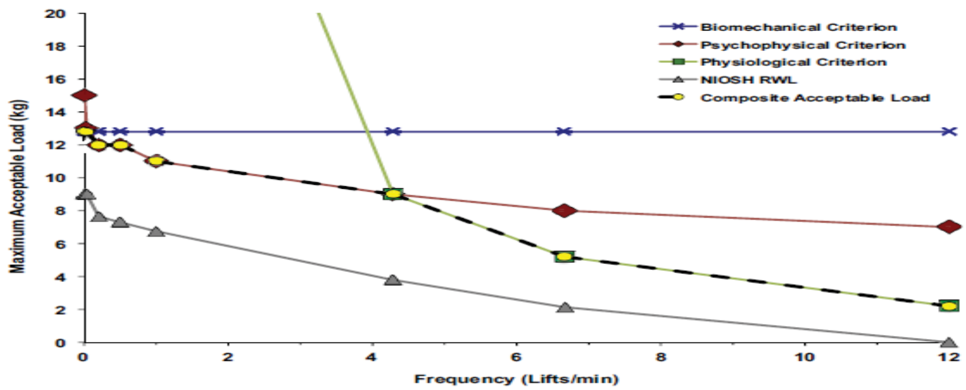

Figure 1: Example showing the integration of the biomechanical, psychophysical and physiological criteria to determine CAL values for each frequency for one condition (K-S range, D ¼ 51 cm, box width ¼ 75 cm). The composite acceptable load (CAL) was assumed to be the most conservative of the three criteria, (Source: Potvin, 2014).

C. Comparison of standard and revised equation-

Comparison between 1981 standard NIOSH lifting equation and the revised NIOSH lifting equation has been given in Table 5, (Weames et al. 1994).

Table 5: Comparison of standard and revised NIOSH equation

	Standard NIOSH Lifting Equation	Revised NIOSH Lifting Equation
Standard Lifting Location	inches above the floor and 6 inches horizontally forward of the mid-point between the ankles	30 inches above the floor and the horizontal dimension has been increased to 10 inches
Load Constant	90 pounds (40 kg)	51 pounds (23 kg)
Calculated Limits	Action Limit (AL), Maximum Permissible Limit (MPL= 3AL)	Recommended Weight Limit (RWL), Lifting Index (LI<=1.0)
Multiplicative Weighting Factors	horizontal, vertical, distance, and frequency	two new ones - asymmetry and coupling
Analysis Procedure	Single-task analysis procedure	Multi-task analysis procedure

Use of NIOSH Equation for multi-task analysis:

Multi-task analysis uses the single task RWL equation and additional indices to determine the overall cumulative physical demands of the lifting station. Multitask analysis is used in lifting operations where weights and heights vary, (Temple and Adams, 2000).

Calculation of VLI for the NIOSH Equation:

The Variable Lifting Index (VLI) can be calculated by first knowing the Frequency Independent Lifting Index (FILI) for each of the tasks that are selected for analysis, then depending upon the task variability each of the lifts is fitted into FILI categories (one to nine). These values and the corresponding frequency of lifts in each category are then input into the Composite Lifting Index (CLI), (Waters et al. 2009).

D. Assumptions-

Phinder et al. (2011) stated the following assumptions under which the NIOSH Lifting Equation is to be considered (these would not hold if the lifting factors were interdependent):

- Lifting factors are independent of each other
- Effects of multipliers are co-operative
- Each factor contributes about the same amount of risk to the overall risk of low-back injury due to a given lifting task, (Phinder et al. 2011).

E. Applications-

At construction sites to know maximum LI of all construction materials and make recommendations:

Choi et al. (2012) stated that; for construction workers to reduce their exposure to risks, they need to know the weights of common construction materials. Negligence of this would lead to pain or injuries among workers. The results of the study are as given in figure 2. It shows the Lifting Index (LI) with respect to various occupations carried out at the construction site.

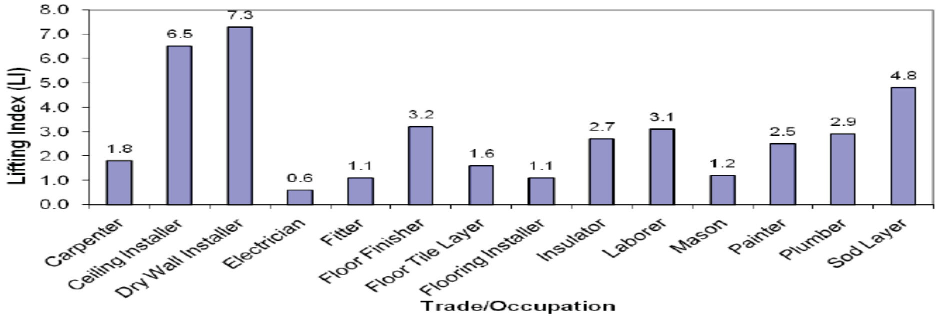

Figure 2: Lifting Index with respect to occupation, (Source: Choi et al., 2012)

The maximum value of the Lifting Index is shown to be 7.3 for Dry Wall Installer so the risk factor for it is the most because the LI shows that it is too heavy. To improve the condition, the improvements that Choi et al. suggested were to:

- Use more than 2 workers
- Use mechanical handling aids
- Use 25% lighter weight drywall

At construction sites to compare LI for materials before and after making optimizations:

Godwin et al. 2013 gave the assessment of Work related Muskuloskeletal Disorders (WMSDs) caused by lifting activities during building construction. The result before and after optimization are shown below in table 6.

Table 6: Lifting Index for various objects before and after optimization, (Source: Godwin et al. 2013).

Object	Weight(kg)	LI=(Weight/RWL)	
		Normal Conditions (RWL=6.83kg)	Optimized Conditions (RWL=23kg)
Bag of Cement	50.0kg	7.32	2.17
9-inch Hollow Block	20.80kg	3.05	0.90
6-inch Hollow Block	16.70kg	2.45	0.73
5-inch Solid Block	22.50kg	3.29	0.93
6-inch Solid Block	26.67kg	3.91	1.16
Full head pan of sand	37.80kg	5.53	1.64
Full head pan of stone	30.30kg	4.44	1.32

At construction sites to calculate LI to know pain caused due to lifting tasks:

Adeyemi et al. (2013) catered to lifting tasks and pain caused due it among workers at construction sites in the Southwestern Nigeria. The results indicated the following:

- More than 70% of the workers are at an increased risk of problems caused by lifting tasks. This is depicted in figure 3.

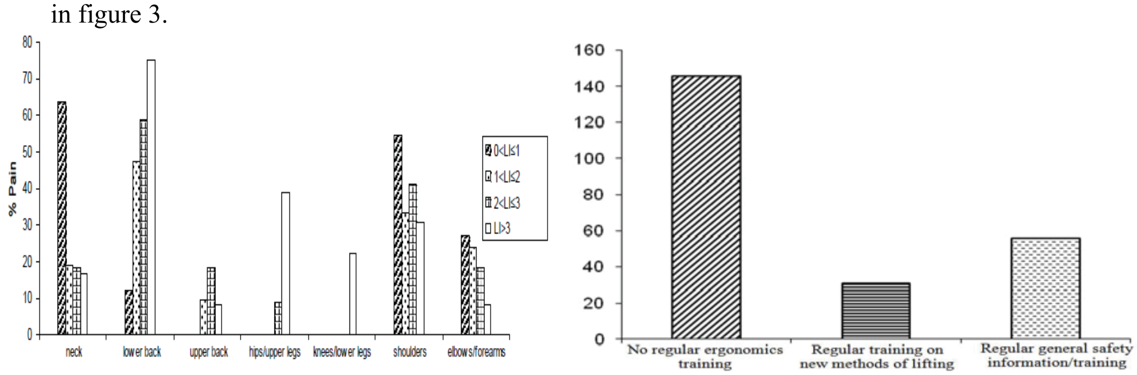

Figure 3: Pain in body regions in 12 months and Response of workers to ergonomics training respectively, (Source: Adeyemi et al. 2013)

- Level of ergonomics training to workers for working methods was found to be low. This is depicted in figure 3.
- Redesigning of work methods was found to be necessary to reach the acceptable LI value.

At casting firms to calculate LI to assess risks due to various lifting tasks:

Singh (2013) studied the low back injury risk and work factors in few small scale casting firms of Northern India for a total of 40 workers. The result of the study was the risk level based on the Lifting Index calculated using the equation. Also, the percent of workers for whom actions need to be taken were calculated and the result is tabulated in the table 7, (Singh, 2013).

Table 7: Lifting index values based on various tasks at the casting firms and their analysis, (Source: Singh, 2013)

Lifting Index	Risk level	Actions	Number of workers	Percentage of workers (%)
0-1	Safe	None necessary	6	15
1-2	Low	Necessary	13	32.5
2-3	Medium	Necessary soon	11	27.5
3 and above	High	Necessary now	10	25

At auto parts manufacturing firm to know LBP level before and after redesign:

Meepradit et al. 2015 considered 17 samples working in auto parts manufacturing. The job was to lift boxes of varying sizes, ranging from 15.7 to 28.7 pounds with duration of 1 to 4 hours a day. The following were the outcomes of the study, (Meepradit et al. 2015):

- Questionnaires for workers for the analysis of musculoskeletal symptoms on a scale ranging from 0 (no pain) to 10 (worst pain) before and after redesign.
- The ergonomics redesigns included:
  1) Load being brought closer to the worker (by training);
  2) Height of objects being placed to be raised (to reduce the vertical distance between the origin and destination of the lift);
  3) Origin and destination of lift to be brought closer (to reduce the angle of twist).
- The new procedures were trained to the workers.
- The result was a safer LI (<1.0) as shown on table 8.

Table 8: Low Back Pain level among workers, (Source: Meepradit et al. 2015)

Low Back Pain Level	Worker (n=17)	
	Before redesign	After redesign
0	0	0
1	0	0
2	1	3
3	1	0
4	1	3
5	3	4
6	2	5
7	3	1
8	0	1
9	3	0
10	3	0

To compare MAWL and Heart rate values of Construction workers and Household Workers:

Maiti and Ray (2004) conducted a study to know the Maximum Acceptable Weight Limit (MAWL) for ten Indian adult female Construction Workers (CW) and eight Indian adult Female household workers (HW). The results of the study are as shown in figure 4. These women were regularly over-exerted at work. Their MAWL was found to be 15kg which is half of the safe load limit (30kg) for adult female workers.

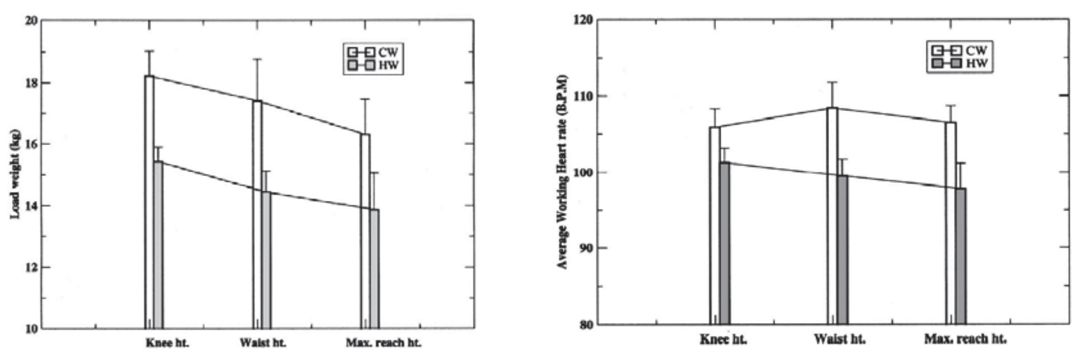

Figure 4: Average MAWL for three vertical distances for CW and HW, and Average heart rate values for CW and HW respectively, (Source: Maiti and Ray, 2004)

The effect of work duration on heart rate is given in figure 4. Heart Rate was calculated to help estimate the MAWL level for variable work duration, (Maiti and Ray, 2004).

At hospitals to know weight of patients that will be safe for nurses to lift:

Waters (2007) took into consideration a study regarding the weight of patients that would be safe for nurses to lift. The results obtained under the following three conditions using the NIOSH Lifting Equation are:

- A nurse raising a patient's leg off the bed for surgery: table 9 shows the results of the study under this condition by Waters (2007).

Table 9: Weight beyond the Maximum Weight that the nurse has to lift

Patient's weight	Weight of leg	Maximum limit	Excess weight to be lifted by nurse
150lbs	24lbs	35lbs	-
200lbs	31lbs	35lbs	-
250lbs	39lbs	35lbs	4lbs
300lbs	47lbs	35lbs	12lbs

Suggestion: use a leg lift or limb positioned, (Waters, 2007).

- Two nurses helping a patient to stand from a chair. Details are as shown in table 10.

Table 10: Excessive weight to be lifted by the nurse

Patient's weight	Weight patient can lift on his own	Maximum limit	Weight to be lifted by each nurse	Excess weight to be lifted by each nurse
180lbs	90lbs	35lbs	45lbs	10lbs

Suggestion: use a lifting device or a sit-to-stand device, (Waters, 2007).

- Four nurses moving a fully dependent patient weighing 200 lbs. from a bed to a wheelchair. Each would lift 50 lbs which exceeds the recommended limit by 15lbs.

Suggestion: use a lifting-assist device, (Waters, 2007).

At wine yard to know risk involved during lifting and make improvements:

Meyers et al. (2006) suggested that manual wine-grape harvesting is highly strenuous and physically demanding work, involving risks of chronic back injury. The findings showed the physical impact of work had a large increase in WMSD symptoms on workers during the standard-tub trial (70% of workers reporting symptoms). Thus, the standard tubs were replaced by smaller picking tubs, the outcome was that the LI reduced from 3.4 to 2.4, (Meyers et al. 2006).

F. Drawback of the NIOSH Lifting Equation-

Dempsey (2002) indicated in his study that problem was caused in using the equation when certain situations such as those mentioned in table 11 arose. The result of his study indicating the problematic situations is given in table 16

Table 11: Result of survey showing jobs not amenable to inclusion, (Source: Dempsey, 2000)

Category	Percentage of Jobs
Variable Weights (>4.5kg)	63%
Job changes often	25%
Job rotation	23%
Too many tasks to analyze	23%
No two-handed lifting	15%
Frequency too high	15%
Workers not willing	3%
Language Barriers	3%

IV.CONCLUSION

The NIOSH Lifting Equation has its application in a variety of fields to reduce the Low Back Pain caused by manual lifting tasks at workplaces. Most of the literature studies have covered its evolution based on the three criteria (Biomechanical, Physiological and Psychophysical), derivation of the equation, and its applications at construction sites, vineyard, industrial organizations, hospital etc. The study is applicable in knowing the effectiveness of lifting operations to ensure safe working practices.

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