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Manual Lifting: The Revised NIOSH Lifting Equation For Evaluating Acceptable Weights for Manual Lifting

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More than ten years ago, the National Institute for Occupational Safety and Health (NIOSH) recognized the growing problem of work-related back injuries and published the *Work Practices Guide for Manual Lifting* (WPG, 1981). The WPG contained a summary of the lifting-related literature before 1981; analytical procedures including a lifting equation for calculating a recommended weight for specified symmetrical two-handed lifting tasks; and certain recommendations for controlling the hazards of low back injury from manual lifting. The approach to hazard control was coupled to the Action Limit (AL), a calculated term that denoted the recommended weight limit derived from the lifting equation, above which "action" was required to reduce the risk injury.

Development of the Revised Equation: In its continuing program of providing guidelines to help control lifting related back injuries, NIOSH has updated their WPG by issuing a *revised lifting equation*. The *revised lifting equation* reflects the results of new research, covers a wider range of tasks, and is more protective of workers compared with the earlier WPG equation.

In 1985, an ad hoc committee of experts was convened by NIOSH to review the current literature on lifting including the WPG. The Project to revise the WPG has resulted in the publication of three primary documents -- an ***updated NTIS literature review*** [1](LR, 1991), a ***revised NIOSH equation journal article*** [2](RE, 1993), and a detailed ***revised equation Applications Manual*** [3](REAM, 1994):

(1) Scientific Support Documentation for the Revised 1991 Lifting Equation: Technical Contract Reports. May 8, 1991, National Technical Information Service, Springfield, Virginia.

(2) Revised NIOSH Equation for the Design and Evaluation of Manual Lifting Tasks, Ergonomics, July 1993, Vol. 36, No. 7, 749-776.

(3) Applications Manual for the Revised NIOSH Lifting Equation, DHHS (NIOSH) Publication No. 94-110, January 1994.

NOTE: While the revised equation was available to select safety and health professions in 1993, the publication of the *Applications Manual for the Revised NIOSH Lifting Equation* in 1994 made the revised equation available to general industry.

The *literature review* (LR, 1991) contains updated information on the physiological, biomechanical, psychophysical, and epidemiological aspects of manual lifting. This formed the basis used by the ad hoc committee of experts to recommend criteria for defining the lifting capacity of healthy workers. The literature review does not contain the revised lifting equation. However, the revised equation was distributed in 1991 by NIOSH staff to attendees at an Ann Arbor, Michigan conference entitled *A National Strategy for Musculoskeletal Injury Prevention -- Implementation Issues and Research Needs*.

The *revised equation* (RE, 1993) provided a more widespread distribution of the revised equation, explains the biomechanical, physiological, and psychophysical criterion used for its development, and provides a description of the derivation of its individual components. The article points out the need for appropriate studies to determine the effect of the recommended methods on the injury morbidity associated with manual materials handling, particularly two-handed lifting tasks.

The *Applications Manual* (REAM, 1994) explains how to apply the revised lifting equation through the use of examples including step-by-step instructions. A copy of the *journal article* (RE, 1993) is included in the appendix of the *Applications Manual*.

The following is a recap of the significant dates associated with the *revised lifting equation*:

1985, the ad hoc committee of experts was convened;

1991, the *literature review* (LR, 1991) was published and the *revised lifting equation* was presented at a conference in Ann Arbor, Michigan;

1993, the *journal article* containing the *revised equation* (RE, 1993) and describing the rationale for selecting the criteria and the determination of the revised lifting equation values was published;

1994, the *Applications Manual* (REAM, 1994) containing detailed examples showing how to apply the *revised lifting equation* was published.

Significant differences between the *work practices guide* (WPG, 1981) and the *revised lifting equation* (RE, 1993) are outlined as follows:

Standard Lifting Location: The *standard lifting location* serves as a three-dimensional reference point for evaluating the worker's lifting posture. In 1981 the standard lifting location was defined as a point located 30 inches above the floor and 6 inches horizontally forward of the mid-point between the ankles. The revised standard lifting location is still 30 inches above the floor but the horizontal dimension has been increased to 10 inches to conform to the results of recent research on how workers lift.

Load Constant: The *load constant* corresponds to the lifting load limit calculated for ideal conditions at the standard lifting location. In 1981 the load constant was 90 pounds. The load constant for the revised equation is 51 pounds. Lifting a weight of 51 pounds at 10 inches forward of the midpoint between the ankles results in about the same compressive force on the spine as lifting a weight of 90 pounds at 6 inches forward of the midpoint between the ankles.

Calculated Limits, WPG 1981: The 1981 lifting guide resulted in two *calculated lifting limits* for a particular lifting task. The lower of the two limits was designated the **Action Limit** (AL). The upper limit was defined as three times the AL and was designated the **Maximum Permissible Limit** (MPL). A lifting task was evaluated by comparing the weight lifted with the two calculated limits for that task (AL and MPL). Lifting of weights below the AL was considered to be associated with an acceptably low risk of injury for most industrial workers. The maximum possible AL, given ideal lifting conditions, was 90 pounds. For weights of lift above the calculated AL, some "action" was required; and the preferred action was to utilize engineering controls (redesign of the lifting task) to eliminate manual lifting above the AL. Where engineering controls were not reasonably feasible to control lifting hazards, management could chose to utilize administrative controls to protect workers in lifting weights above the AL, but below the MPL. In such cases, only rigorous administrative controls such as, medical monitoring, strength testing, and special training were considered acceptable to qualify individual workers. Lifting of weights greater than the MPL was considered unreasonably dangerous for all workers regardless of strength or training.

Calculated Limits, Revised Equation: The *revised lifting equation* results in two calculated values. The first is the **Recommended Weight Limit** (RWL) which corresponds to the AL in terms of acceptable weight of lift. The maximum possible RWL is 51 pounds. The second value is the **Lifting Index** (LI) which is defined as the actual weight lifted divided by the RWL. The LI gives a relative indication of the risk of injury associated with various lifting tasks. Available data does not allow prediction of the magnitude of risk for any individual or the exact percent of the work population who would be at an elevated risk for back injury as the LI increases above 1.0. The NIOSH perspective is that it is likely that tasks with a LI >1.0 pose an increased risk of lifting related injury. Hence the goal should be to design all lifting jobs for LI of 1.0 or less.

Multiplicative Weighting Factors: The *revised lifting equation* retains the use of the four types of multiplicative weighting factors used in 1981 (*horizontal, vertical, distance,* and *frequency*) but adds two new ones (*asymmetry* and *coupling*) for a total of six multipliers. This allows the *revised lifting equation* to be applied to additional lifting tasks not previously covered by providing a multiplier to use when *twisting* is involved and when the *hand-holds* by which the worker grasps the object are less than ideal. The numerical values of the multipliers found in both equations are modified in the *revised lifting equation*.

Multi-task Analysis Procedures: Multi-task analysis procedures for tasks such as loading or unloading a pallet with several tiers of cartons are provided by the *revised lifting equation* and are different to the procedures utilized in the earlier WPG. The details of this analysis, however, are beyond the scope of this writing.

A Reasonable Revised Equation Workplace Application Date: While the *revised lifting equation* has been referred to as "*the 1991 lifting equation*," here it is referred to merely as the *revised lifting equation* or simply the *revised equation*. Although the *revised equation* was presented to select professionals at a conference in Ann Arbor in 1991, it was not readily available to a wide national audience until its July, 1993 publication in the professional journal *Ergonomics*. July 1993, therefore, is the *earliest* date at which it could reasonably be expected that ergonomic, human factors, and safety specialists would begin to use the *revised equation* for evaluating existing or proposed manual lifting tasks. While the article did include the *revised equation*, its primary focus was to explain the derivation of the equation. Detailed instructions on how to apply the *revised equation* awaited publication of the *Applications Manual* (REAM, 1994).

The *Applications Manual for the Revised NIOSH Lifting Equation* is dated January 1994 and became available for purchase after that date. It is intended for use by safety, health, ergonomics, and human factors engineers, managers, and related professionals who are concerned with the use and application of the revised equation to evaluate workplace lifting tasks. It provides a more complete description of the method and limitations for using the *revised equation* than did the 1993 article.

Objectives of the Lifting Equations: The objective of both the 1981 equation and the *revised equation* is to prevent or reduce the occurrence of lifting-related low back pain and injury among workers. The *revised equation* reflects new findings and expands the number of tasks that can be evaluated by providing methods for evaluating asymmetrical lifting tasks, lifts of objects with less than optimal hand-container couplings, and also by providing guidelines for a larger range of work durations and lifting frequencies than the 1981 equation. The *revised equation* is more protective of workers and can be applied to tasks not included in the 1981 guideline.

Capabilities and Limitations in Regard to the Application of the Revised Lifting Equation: The *lifting equation* is a tool for assessing the physical stress of two-handed manual lifting tasks. Its application is limited to the conditions for which it was designed, encompassing specific criteria for lifting related to stated biomechanical, work physiology, and psychophysical assumptions and data. Task limitations are listed below.

1. The *revised lifting equation* is based on the assumption that other manual material handing activities are minimal (less than about 10% of worker activity). Examples of such activities include holding, pushing, pulling, carrying, and climbing. The equation will still apply if holding and carrying are minimal, but holding should not exceed a few seconds and carrying should be limited to one or two steps.

2. The *revised lifting equation* does not include factors to account for unpredicted conditions such as unexpectedly heavy or suddenly applied loads, slips, falls, traumatic incidents or unfavorable environmental conditions including either low or high ambient temperature or humidity.

3. The *revised lifting equation* was not designed to assess lifting tasks involving one-handed lifting, lifting while seated or kneeling, or lifting in a constrained or restricted workspace. It also does not apply to lifting and maneuvering wheelbarrows, shoveling, high speed lifting, or the lifting of unstable loads, such as some containers of liquid or incompletely filled bags, etc.

WORKER SELECTION

If a job cannot be redesigned to meet the RWL, some experts believe that worker selection criteria may be used to identify workers who can perform potentially stressful lifting tasks (LI > 1.0) without significantly increasing their risk of work-related injury. Those selection criteria, however, must be based on research studies, empirical observations, or theoretical considerations that include job-related strength testing and/or aerobic capacity testing. Nonetheless, these experts agree that nearly all workers will be at an increased risk of work-related injury when performing highly stressful lifting tasks (i.e. lifting tasks that would exceed a LI of 3.0).

Revised Equation for Calculation of Recommended Weight Limit: The *revised equation* is represented mathematically by the following expression (US customary units):

Recommended Weight Limit (**RWL)**

= (LC)(HM)(VM)(DM)(AM)(FM)(CM)

Where:

LC = load constant = (51 lbs)

HM = horizontal multiplier = (10/H)

VM = vertical multiplier = [1 - (0.0075 |V - 30|)]

DM = distance multiplier = [0.82 + (1.8/D)]

AM = asymmetric multiplier = [1 -(0.0032A)]

FM = frequency multiplier (see Table 5)

CM = coupling multiplier (see Table 7)

LI = lifting index = (weight lifted/RWL)

W = container width in sagital plane (inches).

NOTE: Sagital means "front to back".

H = *horizontal distance (in inches) of the hands at the midpoint of hand-grip from midpoint between the ankles*. Where significant control is required at the destination of the lift, H is measured both at the origin and destination points. The most stressful H will then be used in the calculation. Where H cannot be measured, H may by approximated by one of the following rules. Where V $\geq$ 10 inches, H = 8+W/2. Where V < 10 inches, H = 10+W/2.

NOTE: Some limits are also imposed on HM. For those cases where H $\leq$ 10 inches, HM is set equal to 1.0. If H > 25 inches, then HM is set equal to zero (0).

V = *vertical distance (in inches) of the hands from the floor at the origin of the lift measured vertically from the floor to the mid-point between the hand grasps, as defined by the large middle knuckle*. Where significant control is required at the destination of the lift, V is measured at the origin and destination of the lift (inches). The most stressful V will then be used in the calculation. If V > 70 inches, then VM is set equal to zero (0).

D = *vertical travel distance between the origin and the destination of the lift (in inches)*. For a lowering task, D is set equal to V at the origin minus V at the destination. If D < 10 inches, then set D = 10 inches.

A = *angle of asymmetry; that is, angular displacement of the load (required pivot) from the sagittal plane*. The sagittal plane extends vertically from front to back in the body's median plane (a plane dividing the body left and right). This angle is measure at the origin and the destination of the lift (degrees). The asymmetric angle (A) is defined as the angle between the asymmetry line and the mid-sagittal line. The asymmetry line is defined as the horizontal line that joins the mid-point between the inner ankle bones and the point projected on the floor directly below the mid-point of the hand grasps, as defined by the large middle knuckle. The sagittal line is defined as the line passing through the mid-point between the inner anklebones and lying in the mid-sagittal plane, as defined by the neutral body position (i.e., hands directly in front of the body, with no twisting at the legs, torso, or shoulders). In many cases of asymmetric lifting, the worker will pivot or use a step turn to complete the lift. Since this may vary between workers and between lifts, assume no pivoting or stepping occurs. Although this assumption may overestimate the reduction in acceptable load weight, it will provide the greatest protection for the worker. The asymmetry angle (A) is limited to the range from 0^0 to 135^0. If A > 135^0, then AM is set equal to zero (0).

The *frequency multiplier* (FM) value is determined from Table 5. For repetitive lifting tasks, FM is determined by (a) the number of lifts per minute (frequency) over a 15 minute period, (b) the amount of time engaged in the lifting activity (duration), and (c) the vertical height of the lift from the floor. Short duration is defined as $\leq$ 1 hr followed by a recovery period of at least 1.2 times the duration of lifting. Moderate duration is defined as > 1 hr, but $\leq$ 2 hr followed by a recovery period of at least 3 times the lifting duration. If the required recovery duration is not met, and subsequent lifting is required, then total lifting time is combined to determine the correct duration category. Long duration is defined as > 2 hr but ≤ 8 hr including standard industrial rest allowances (e.g. morning, lunch, and afternoon rest breaks). For lifting tasks with a frequency < .2 lifts/minute, frequency is set = .2 lifts/minute. For infrequent lifting (F < .1 lift/minute), the recovery period will usually be sufficient to use the 1-hr duration category. No weight limits are provided for more than 8 hours of work. For occasional (non-repetitive) lifting tasks, FM = 1. The *coupling multiplier* (CM) is found in Table 7 after first determining V and the hand-to-container coupling classification outlined in Table 6. A good coupling will reduce the maximum grasp forces required and increase the maximum acceptable weight of lift, while a poor coupling will generally require higher maximum grasp forces and decrease the acceptable weight of lift. If there is doubt about classifying a particular coupling design, the more stressful classification should be selected.

The *lifting index* (LI) provides a relative estimate of the level of physical stress associated with a particular lifting task. It is defined by the relationship of the weight of load lifted (L) and the recommended weight limit (RWL). In equation form this index is LI = L/RWL.

SUMMARY

1. Due to the use of a more realistic estimate of the distance in front of the body at which lifting is performed, NIOSH has lowered the acceptable weight of lift for industrial workers under ideal conditions from 90 pounds to 51 pounds.

2. NIOSH no longer sanctions the use of administrative controls to qualify individual workers to lift weights greater than the recommended limit. The only acceptable controls in such cases are engineering controls.

3. NIOSH's approach to manual lifting appears to have been brought into line with their general approach to setting limits for exposure to hazardous conditions or substances (TLV's, etc.).

4. The *revised lifting equation* provides an authoritative and readily available guideline for evaluating most existing or proposed lifting tasks in order to protect most workers from manual lifting injury. An alternative evaluation may be provided by an in-depth analysis of specific tasks by a qualified ergonomic specialist.

For further information about the control of manual lifting hazards associated with the handling of excessive weight, request the following Nelson & Associates Fact Sheets:

"Manual Lifting: Historical Sources of Current Standards Regarding Acceptable Weights of Lift"

"Manual Lifting: The NIOSH Work Practices Guide for Manual Lifting - Determining Acceptable Weights of Lift" (Effective from March 1981 to July 1994)."

"Manual Lifting: Training Programs in Manual Materials Handling"

"Manual Lifting: Product Design and Labeling"

APPENDIX A

Tables of Multiplier Values

Table 1

Horizontal Multiplier

H inches	HM
≤10	1.00
11	.91
12	.83
13	.77
14	.71
15	.67
16	.63
17	.59
18	.56
19	.53
20	.50
21	.48
22	.46
23	.44
24	.42
25	.40
>25	.00

Table 2

Vertical Multiplier

V inches	VM
0	.78
5	.81
10	.85
15	.89
20	.92
25	.96
30	1.00
35	.96
40	.93
45	.89
50	.85
55	.81
60	.78
65	.74
70	.70
>70	.00

Table 3

Distance Multiplier

D inches	DM
≤10	1.00
15	.94
20	.91
25	.89
30	.88
35	.87
40	.87
45	.86
50	.86
55	.85
60	.85
70	.85
>70	.00

Table 4

Asymmetric Multiplier

A degrees	AM
0	1.00
15	.95
30	.90
45	.86
60	.81
75	.76
90	.71
105	.66
120	.62
135	.57
>135	.00

Table 5

Frequency Multiplier Table (FM)

Frequency Lifts/Min (F)*	**Work Duration**					
	≤1 Hour		>1 but ≤2 Hrs.		>2 but ≤8 Hrs.	
	V<30	V≥30	V<30	V≥30	V<30	V≥30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

NOTE: For lifting less frequently than once per 5 minutes, set F= 0.2
Values of V are in inches.

Table 6

Hand-to-Container Coupling Classification

GOOD	FAIR	POOR
1. For containers of optimal design, such as some boxes, crates, etc., a "Good" hand-to-object coupling would be defined as handles or hand-hold cut-outs of optimal design (see notes 1 to 3 below).	1. For containers of optimal design, a "Fair" hand-to-object coupling would be defined as handles or hand-hold cut-outs of less than optimal design (see notes 1 to 4 below).	1. Containers of less than optimal design of loose parts or irregular objects that are bulky, hard to handle, or have sharp edges (see note 5 below).
2. For loose parts or irregular objects which are not usually containerized, such as castings, stock, and supply materials, a "Good" hand-to-object coupling would be defined as a comfortable grip in which the hand can be easily wrapped around the object (see note 6 below).	2. For Containers of optimal design with no handles or hand-hold cut-outs or for loose parts or irregular objects, a "Fair" hand-to-object coupling is defined as a grip in which the hand can be flexed about 90 degrees (see note 4 below).	2. Lifting non-rigid bags (i.e., bags that sag in the middle).

1. An optimal handle design has 0.75 - 1.5 inches diameter, $\geq$4.5 inches length, 2 inches clearance, cylindrical shape, and a smooth, non-slip surface.
2. An optimal hand-hold cut-out has the following approximate characteristics: $\geq$1.5 inch height, 4.5 inch length, semi-oval shape, $\geq$2 inches clearance, smooth, non-slip surface, and $\geq$0.25 inches container thickness (e.g., double thickness cardboard).
3. An optimal container design has $\leq$16 inches frontal length, $\leq$12 inches height, and a smooth non-slip surface.
4. A worker should be capable of clamping the fingers at nearly 90^0 under the container, such as required when lifting a cardboard box from the floor.
5. A container is considered less than optimal if it has a frontal length >16 inches, height >12 inches, rough or slippery surfaces, sharp edges, asymmetric center of mass, unstable contents, or requires the user of gloves. A loose object is considered bulky if the load cannot easily be balanced between the hand-grasps.
6. A worker should be able to comfortably wrap the hand around the object without causing excessive wrist deviations of awkward postures, and the grip should not require excessive force.

Table 7

Coupling Multiplier (CM)

Coupling Type	**Coupling Multiplier**	
	V<30 inches	V$\geq$30 inches
Good	1.00	1.00
Fair	.95	1.00
Poor	.90	.90

APPENDIX B

An Example of Using the NIOSH Revised Lifting Equation to Evaluate a Lifting Task

JOB DESCRIPTION

Cartons of product are accumulated on the floor adjacent to a conveyor. The job consists of a worker lifting the cartons from the floor and placing them on the conveyor. The height of the conveyor is 24 inches. The cartons are 12" high, 12" wide, and 16" long. Carton weight is 20 pounds. Frequency of lift is .2 lifts per minute and the duration of the task is between 1 and 2 hours. The cartons have no handholds. Control at the destination of lift is not required. The angle of asymmetry at the origin of lift may be taken to be 45 degrees.

JOB ANALYSIS

The first step is to determine the **task variables**.

Note: H may be estimated according to:
H = 10 + W/2

Task Variables:

H	=	10 + W/2
	=	10 + 12/2
	=	10 + 6
	=	16
V	=	0
D	=	24
A	=	45 degrees
F	=	.2/minute
C	=	fair (see table 6)

The second step is to determine the **multipliers** to use in the NIOSH equation.

Note: HM, VM, DM, and AM may be calculated or simply read from Tables 1, 2, 3, and 4 respectively. FM is taken from table 5 and CM is taken from Table 7.

MULTIPLIERS

HM	=	0.63 (Table 1)
VM	=	0.78 (Table 2)
DM	=	0.89 (Table 3)
AM	=	0.86 (Table 4)
FM	=	0.95 (Table 5)
CM	=	.95 (Table 7)

The third step is to calculate the NIOSH Recommended Weight Limit (RWL).

RWL = (51)(HM)(VM)(DM)(AM)(FM)(CM)

= (51)(0.63)(0.78)(0.89)(0.86)(0.95)(0.95)

= 17.3 pounds

The final step is to calculate the Lifting Index (LI).

LI = Object Weight / RWL

= 20 / 17.3

= 1.2

PRELIMINARY RESULTS

The object weight is greater than the recommended weight limit (LI>1.0). From the NIOSH perspective, it is likely that lifting tasks with a LI > 1.0 pose an increased risk for lifting-related low back pain for some fraction of the workforce.

JOB REDESIGN

One feasible job redesign might be to utilize a rack to accumulate the cartons rather than the floor. Assuming 18 inches would be a convenient rack height, the effect of this change in the job can be evaluated as follows:

TASK VARIABLES

H	=	16
V	=	18
D	=	6
A	=	45 degrees
F	=	0.2/minute
C	=	fair (see Table 6)

MULTIPLIERS

HM	=	0.63 (Table 1)
VM	=	0.91 (Table 2)
DM	=	1.00 (Table 3)
AM	=	0.86 (Table 4)
FM	=	0.95 (Table 5)
CM	=	0.95 (Table 7)

RWL = (51)(HM)(VM)(DM)(AM)(FM)(CM)

= (51)(0.63)(0.91)(1.0)(0.86)(0.95)(0.95)

= 22.7 pounds

LI = Object Weight / RWL

= 20 / 22.7

= 0.9

CONCLUSIONS

The job redesign has resulted in a RWL that is larger than the object weight (LI < 1.0). Nearly all healthy workers could perform this job without an increased risk of developing lifting-related low back pain.