INTRODUCTION

Low back pain (LBP) and injuries attributed to manual lifting activities continue as one of the leading occupational health and safety issues facing preventive medicine. Despite efforts at control, including programs directed at both workers and jobs, work-related back injuries still account for a significant proportion of human suffering and economic cost to this nation. The scope of the problem was summarized in a report entitled *Back Injuries*, prepared by the Department of Labor's Bureau of Labor Statistics [DOL(BLS)], Bulletin 2144, published in 1982.

The DOL's conclusions are consistent with current workers' compensation data indicating that "injuries to the back are one of the more common and costly types of work-related injuries" (National Safety Council, 1990). According to the DOL report, back injuries accounted for nearly 20% of all injuries and illnesses in the workplace, and nearly 25% of the annual workers' compensation payments. A more recent report by the National Safety Council (1990) indicated that overexertion was the most common cause of occupational injury, accounting for 31% of all injuries. The back, moreover, was the body part most frequently injured (22% of 1.7 million injuries) and the most costly to workers' compensation systems.

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* (NIOSH WPG, 1981). The NIOSH WPG (1981) contained a summary of the lifting-related literature before 1981; analytical procedures and a lifting equation for calculating a recommended weight for specified two-handed, symmetrical lifting tasks; and an approach for controlling the hazards of low back injury from manual lifting. The approach to hazard control was coupled to the Action Limit (AL), a resultant term that denoted the recommended weight derived from the lifting equation.

In 1985, the National Institute for Occupational Safety and Health (NIOSH) convened an ad hoc committee of experts who reviewed the current literature on lifting, including the NIOSH WPG (1981).[1] The literature review was summarized in a document entitled *Scientific Support Documentation for the Revised 1991 NIOSH Lifting Equation: Technical Contract Reports, May 8, 1991*, which is available from the National Technical Information Service [NTIS No. PB-91-226-274]. The literature summary contains updated information on the physiological, biomechanical, psychophysical, and epidemiological aspects of manual lifting. Based on the results of the literature review, the ad hoc committee recommended criteria for defining the lifting capacity of healthy workers. The committee used the criteria to formulate the revised lifting equation. The equation was publicly presented in 1991 by NIOSH staff at a national conference in Ann Arbor, Michigan entitled *A National Strategy for Occupational Musculoskeletal Injury Prevention -- Implementation Issues and Research Needs.*[2] Subsequently, NIOSH staff developed the documentation for the equation and played a prominent role in recommending methods for interpreting the results of the lifting equation.

The revised lifting equation reflects new findings and provides methods for evaluating asymmetrical lifting tasks, and lifts of objects with less than optimal couplings between the object and the worker's hands. The revised lifting equation also provides guidelines for a more diverse range of lifting tasks than the earlier equation (NIOSH WPG, 1981).

The rationale and criterion for the development of the revised

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[1] The ad hoc 1991 NIOSH Lifting Committee members included: M.M. Ayoub, Donald B. Chaffin, Colin G. Drury, Arun Garg, and Suzanne Rodgers.
NIOSH representatives included Vern Putz-Anderson and Thomas R. Waters.

[2] For this document, the revised 1991 NIOSH lifting equation will be identified simply as "the revised lifting equation." The abbreviation WPG (1981) will continue to be used as the reference to the earlier NIOSH lifting equation, which was documented in a publication entitled *Work Practices Guide for Manual Lifting* (1981).

NIOSH lifting equation are provided in a separate journal article entitled: *Revised NIOSH Equation for the Design and Evaluation of Manual Lifting Tasks*, by Waters, Putz-Anderson, Garg, and Fine, 1993. [Appendix I]. We suggest that those practitioners who wish to achieve a better understanding of the data and decisions that were made in formulating the revised equation consult the article by Waters *et al.*, 1993. This article provides an explanation of the selection of the biomechanical, physiological, and psychophysical criterion, as well as a description of the derivation of the individual components of the revised lifting equation. For those individuals, however, who are primarily concerned with the use and application of the revised lifting equation, the present document provides a more complete description of the method and limitations for using the revised equation than does the article by Waters *et al.* 1993. This document also provides a complete set of examples.

Although the revised lifting equation has not been fully validated, the recommended weight limits derived from the revised equation are consistent with, or lower than, those generally reported in the literature (Waters *et al.*, 1993, Tables 2, 4, and 5). Moreover, the proper application of the revised equation is more likely to protect healthy workers for a wider variety of lifting tasks than methods that rely only a single task factor or single criterion.

Finally, it should be stressed that the NIOSH lifting equation is only one tool in a comprehensive effort to prevent work-related low back pain and disability. [Other approaches to prevention are described elsewhere (ASPH/NIOSH, 1986)]. Moreover, lifting is only one of the causes of work-related low back pain and disability. Other causes which have been hypothesized or established as risk factors include whole body vibration, static postures, prolonged sitting, and direct trauma to the back. Psychosocial factors, appropriate medical treatment, and job demands (past and present) also may be particularly important in influencing the transition of acute low back pain to chronic disabling pain.

1. THE REVISED LIFTING EQUATION

This section provides the technical information for using the revised lifting equation to evaluate a variety of two-handed manual lifting tasks. Definitions, restrictions/limitations, and data requirements for the revised lifting equation are also provided.

1.1 Definition of Terms

1.1.1 Recommended Weight Limit (RWL)

The **RWL** is the principal product of the revised NIOSH lifting equation. The RWL is defined for a specific set of task conditions as the weight of the load that nearly all healthy workers could perform over a substantial period of time (e.g., up to 8 hours) without an increased risk of developing lifting-related LBP. By ***healthy workers***, we mean workers who are free of adverse health conditions that would increase their risk of musculoskeletal injury.

The **RWL** is defined by the following equation:

$$\mathbf{RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM}$$

A detailed description of the individual components of the equation are provided in Section 1.3 on pages 12-13.

1.1.2. Lifting Index (LI)

The **LI** is a term that provides a relative estimate of the level of physical stress associated with a particular manual lifting task. The estimate of the level of physical stress is defined by the relationship of the weight of the load lifted and the recommended weight limit.

The **LI** is defined by the following equation:

$$LI = \frac{\textbf{Load Weight}}{\textbf{Recommended Weight Limit}} = \frac{\textbf{L}}{\textbf{RWL}}$$

1.1.2. Terminology and Data Definitions

The following list of brief definitions is useful in applying the revised NIOSH lifting equation. For detailed descriptions of these terms, refer to the individual sections where each is discussed. Methods for measuring these variables and examples are provided in Sections 1 and 2.

Lifting Task	Defined as the act of manually grasping an object of definable size and mass with two hands, and vertically moving the object without mechanical assistance.
Load Weight (L)	Weight of the object to be lifted, in pounds or kilograms, including the container.
Horizontal Location (H)	Distance of the hands away from the mid-point between the ankles, in inches or centimeters (measure at the origin and destination of lift). See Figure 1.
Vertical Location (V)	Distance of the hands above the floor, in inches or centimeters (measure at the origin and destination of lift). See Figure 1.
Vertical Travel Distance (D)	Absolute value of the difference between the vertical heights at the destination and origin of the lift, in inches or centimeters.
Asymmetry Angle (A)	Angular measure of how far the ***object*** is displaced from the front (mid-sagittal plane) of the worker's body at the beginning or ending of the lift, in

	degrees (measure at the origin and destination of lift). See Figure 2. The asymmetry angle is defined by the location of the load relative to the worker's mid-sagittal plane, as defined by the neutral body posture, rather than the position of the feet or the extent of body twist.
Neutral Body Position	Describes the position of the body when the hands are directly in front of the body and there is minimal twisting at the legs, torso, or shoulders.
Lifting Frequency (F)	Average number of lifts per minute over a 15 minute period.
Lifting Duration	Three-tiered classification of lifting duration specified by the distribution of work-time and recovery-time (work pattern). Duration is classified as either short (1 hour), moderate (1-2 hours), or long (2-8 hours), depending on the work pattern.
Coupling Classification	Classification of the quality of the hand-to-object coupling (e.g., handle, cut-out, or grip). Coupling quality is classified as good, fair, or poor.
Significant Control	Significant control is defined as a condition requiring ***precision placement*** of the load at the destination of the lift. This is usually the case when (1) the worker has to re-grasp the load near the destination of the lift, or (2) the worker has to momentarily hold the object at the destination, or (3) the worker has to carefully position or guide the load at the destination.

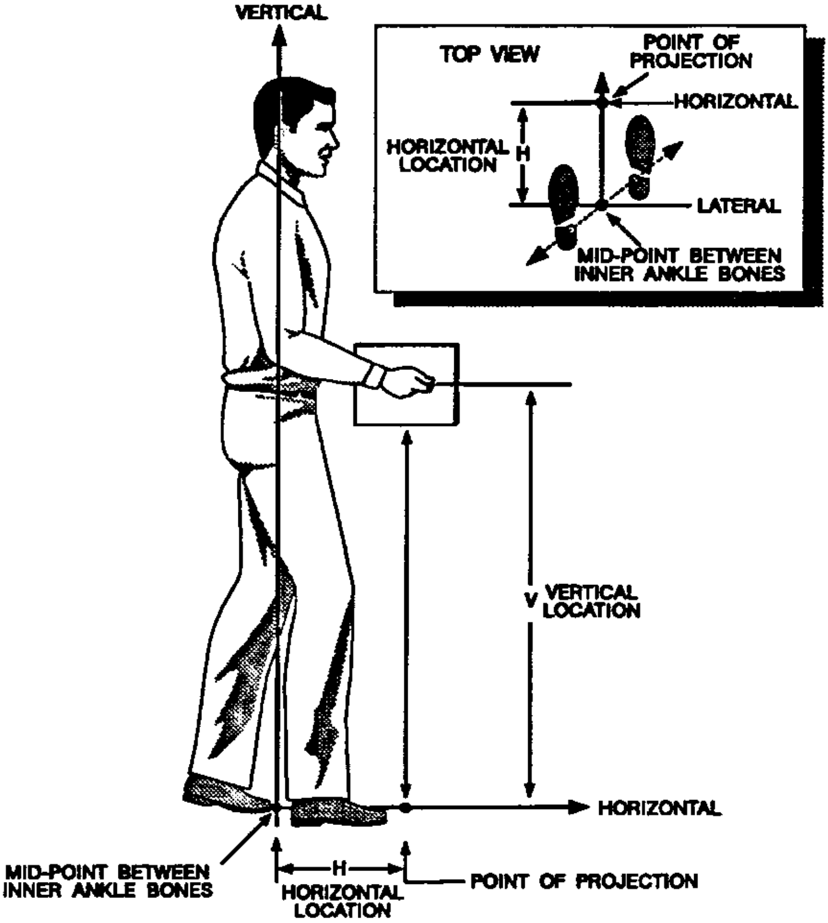

Figure 1 Graphic Representation of Hand Location

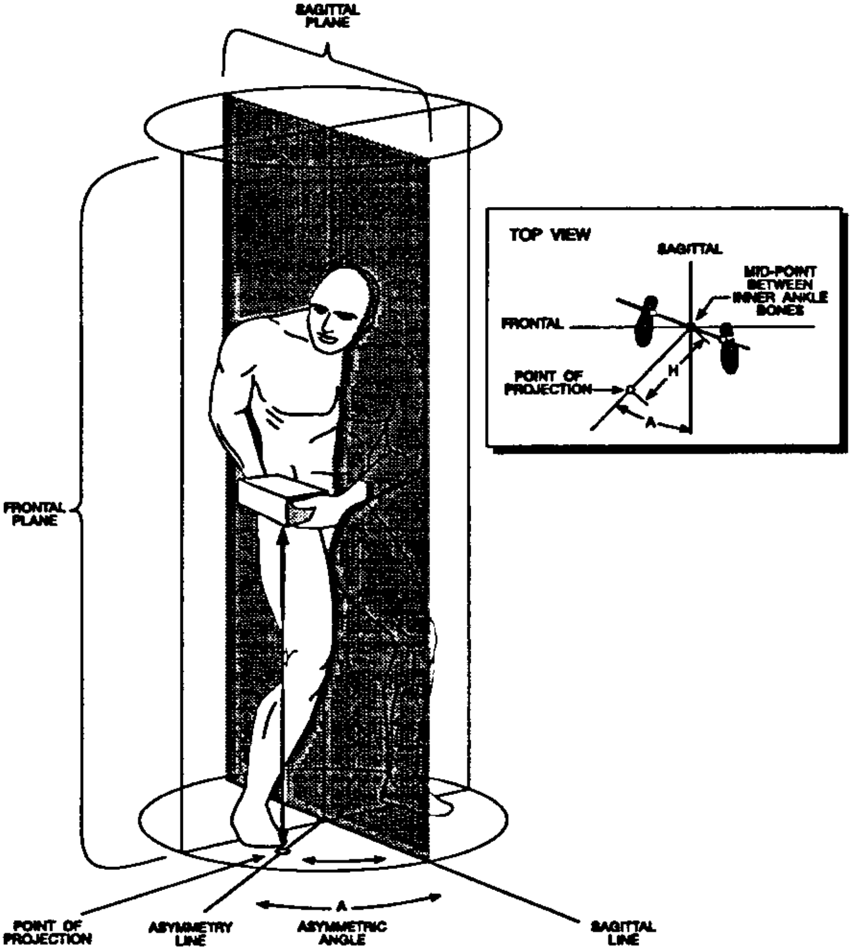

Figure 2 Graphic Representation of Angle of Asymmetry (A)

1.2. Lifting Task Limitations

The lifting equation is a tool for assessing the physical stress of two-handed manual lifting tasks. As with any tool, its application is limited to those conditions for which it was designed. Specifically, the lifting equation was designed to meet specific lifting-related criteria that encompass biomechanical, work physiology, and psychophysical assumptions and data, identified above. To the extent that a given lifting task accurately reflects these underlying conditions and criteria, this lifting equation may be appropriately applied.

The following list identifies a set of work conditions in which the application of the lifting equation could either under- or over-estimate the extent of physical stress associated with a particular work-related activity. Each of the following task limitations also highlight research topics in need of further research to extend the application of the lifting equation to a greater range of real world lifting tasks.

1. The revised NIOSH lifting equation is based on the assumption that manual handling activities other than lifting are minimal and do not require significant energy expenditure, especially when repetitive lifting tasks are performed. Examples of non-lifting tasks include holding, pushing, pulling, carrying, walking, and climbing. If such non-lifting activities account for more than about 10% of the total worker activity, then measures of workers' energy expenditures and/or heart rate may be required to assess the metabolic demands of the different tasks. The equation will still apply if there is a small amount of holding and carrying, but carrying should be limited to one or two steps and holding should not exceed a few seconds. For more information on assessing metabolic demand, see Garg *et al*. (1978) or Eastman Kodak (1986) .

2. The revised lifting equation does not include task factors to account for unpredicted conditions, such as unexpectedly heavy loads, slips, or falls. Additional biomechanical analyses may be required to assess the physical stress on joints that occur from traumatic incidents. Moreover, if the environment is unfavorable (e.g., temperatures or humidity significantly outside the range of 19° to 26°C [66° to 79°F] or 35% to 50%, respectively), independent metabolic assessments would be needed to gauge the effects of these variables on heart rate and energy consumption.

3. The revised lifting equation was not designed to assess tasks involving one-handed lifting, lifting while seated or kneeling, or lifting in a constrained or restricted work space.[3] The equation also does not apply to lifting unstable loads. For purposes of applying the equation, an unstable load would be defined as an object in which the location of the center of mass varies significantly during the lifting activity, such as some containers of liquid or incompletely filled bags, etc. The equation does not apply to lifting of wheelbarrows, shoveling, or high-speed lifting.[4] For such task conditions, independent and task specific biomechanical, metabolic, and psychophysical assessments may be needed. For information on other assessment methods, refer to Eastman Kodak (1986), Ayoub and Mital (1989), Chaffin and Andersson (1991), or Snook and Ciriello (1991).

4. The revised lifting equation assumes that the worker/floor surface coupling provides at least a 0.4 (preferably 0.5) coefficient of static friction between the shoe sole and the working surface. An adequate worker/floor surface coupling is necessary when lifting to provide a firm footing and to control accidents and

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[3] The research staff of the Bureau of Mines have published numerous studies on lifting while kneeling and in restricted workspaces (See Gallagher *et al.*, 1988; Gallagher and Unger, 1990; and, Gallagher, 1991).

[4] Although lifting speed is difficult to judge, a high speed lift would be equivalent to a speed of about 30 inches/second. For comparison purposes, a lift from the floor to a table-top that is completed in less than about 1 second would be considered high speed.

injuries resulting from foot slippage. A 0.4 to 0.5 coefficient of static friction is comparable to the friction found between a smooth, dry floor and the sole of a clean, dry leather work shoe (nonslip type). Independent biomechanical modeling may be used to account for variations in the coefficient of friction.

5. The revised lifting equation assumes that lifting and lowering tasks have the same level of risk for low back injuries (i.e. that lifting a box from the floor to a table is as hazardous as lowering the same box from a table to the floor). This assumption may not be true if the worker actually drops the box rather than lowering it all the way to the destination. Independent metabolic, biomechanical, or psychophysical assessments may be needed to assess worker capacity for various lowering conditions. (See references provided above.)

In summary, the Revised NIOSH Lifting Equation does not apply if any of the following occur:

- Lifting/lowering with one hand
- Lifting/lowering for over 8 hours
- Lifting/lowering while seated or kneeling
- Lifting/lowering in a restricted work space
- Lifting/lowering unstable objects
- Lifting/lowering while carrying, pushing or pulling
- Lifting/lowering with wheelbarrows or shovels
- Lifting/lowering with ***high speed*** motion (faster than about 30 inches/second)
- Lifting/lowering with unreasonable foot/floor coupling (< 0.4 coefficient of friction between the sole and the floor)

- Lifting/lowering in an unfavorable environment (i.e., temperature significantly outside 66-79° F (19-26° C) range; relative humidity outside 35-50% range)

For those lifting tasks in which the application of the revised lifting equation is not appropriate, a more comprehensive ergonomic evaluation may be needed to quantify the extent of other physical stressors, such as prolonged or frequent non-neutral back postures or seated postures, cyclic loading (whole body vibration), or unfavorable environmental factors (e.g., extreme heat, cold, humidity, etc.).

Any of the above factors, alone or in combination with manual lifting, may exacerbate or initiate the onset of low back pain.

1.3. The Equation and Its Function

The revised lifting equation for calculating the Recommended Weight Limit (RWL) is based on a multiplicative model that provides a weighting for each of six task variables. The weightings are expressed as coefficients that serve to decrease the load constant, which represents the maximum recommended load weight to be lifted under ideal conditions. The RWL is defined by the following equation:

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM$$

Where:

		METRIC	U.S. CUSTOMARY
Load Constant	LC	23 kg	51 lb
Horizontal Multiplier	HM	(25/H)	(10/H)
Vertical Multiplier	VM	$1-(.003\|V-75\|)$	$1-(.0075\|V-30\|)$
Distance Multiplier	DM	.82 + (4.5/D)	.82 + (1.8/D)
Asymmetric Multiplier	AM	1-(.0032A)	1-(.0032A)
Frequency Multiplier	FM	From Table 5	From Table 5
Coupling Multiplier	CM	From Table 7	From Table 7

The term ***task variables*** refers to the measurable task descriptors (i.e., H, V, D, A, F, and C); whereas, the term ***multipliers*** refers to the reduction coefficients in the equation (i.e., HM, VM, DM, AM, FM, and CM).

Each multiplier should be computed from the appropriate formula, but in some cases it will be necessary to use linear interpolation to determine the value of a multiplier, especially when the value of a variable is not directly available from a table. For example, when the measured frequency is not a whole number, the appropriate multiplier must be interpolated between the frequency values in the table for the two values that are closest to the actual frequency.

> *A brief discussion of the task variables, the restrictions, and the associated multiplier for each component of the model is presented in the following sections.*

1.3.1. Horizontal Component

1.3.1.1. Definition and Measurement

Horizontal Location (H) is measured from the mid-point of the line joining the inner ankle bones to a point projected on the floor directly below the mid-point of the hand grasps (i.e., load center), as defined by the large middle knuckle of the hand (Figure 1). Typically, the worker's feet are not aligned with the mid-sagittal plane, as shown in Figure 1, but may be rotated inward or outward. If this is the case, then the mid-sagittal plane is defined by the worker's neutral body posture as defined above.

If significant control is required at the destination (i.e., precision placement), then H should be measured at both the origin and destination of the lift.

Horizontal Location (H) should be measured. In those situations where the H value can not be measured, then H may be approximated from the following equations:

Metric [All distances in cm]	U.S. Customary [All distances in inches]
$H = 20 + W/2$ for $V \geq 25$ cm	$H = 8 + W/2$ for $V \geq 10$ inches
$H = 25 + W/2$ for $V < 25$ cm	$H = 10 + W/2$ for $V < 10$ inches

Where: W is the width of the container in the sagittal plane and V is the vertical location of the hands from the floor.

1.3.1.2. Horizontal Restrictions

If the horizontal distance is less than 10 inches (25 cm), then H is set to 10 inches (25 cm). Although objects can be carried or held closer than 10 inches from the ankles, most objects that are closer than this cannot be lifted without encountering interference from the abdomen or hyperextending the shoulders. While 25 inches (63 cm) was chosen as the maximum value for H, it is probably too large for shorter workers, particularly when lifting asymmetrically. Furthermore, objects at a distance of more than 25 inches from the ankles normally cannot be lifted vertically without some loss of balance.

1.3.1.3. Horizontal Multiplier

The Horizontal Multiplier (HM) is 10/H, for H measured in inches, and HM is 25/H, for H measured in centimeters. ***If H is less than or equal to 10 inches (25 cm)***, then the multiplier is 1.0. HM decreases with an increase in H value. The multiplier for H is reduced to 0.4 when H is 25 inches (63 cm). If H is greater than 25 inches, then HM = 0. The HM value can be computed directly or determined from Table 1.

Table 1
Horizontal Multiplier

H	HM	H	HM
in		cm	
≤10	1.00	≤25	1.00
11	.91	28	.89
12	.83	30	.83
13	.77	32	.78
14	.71	34	.74
15	.67	36	.69
16	.63	38	.66
17	.59	40	.63
18	.56	42	.60
19	.53	44	.57
20	.50	46	.54
21	.48	48	.52
22	.46	50	.50
23	.44	52	.48
24	.42	54	.46
25	.40	56	.45
>25	.00	58	.43
		60	.42
		63	.40
		>63	.00

1.3.2. Vertical Component

1.3.2.1. Definition and Measurement

Vertical Location (V) is defined as the vertical height of the hands above the floor. V is measured vertically from the floor to the mid-point between the hand grasps, as defined by the large middle knuckle. The coordinate system is illustrated in Figure 1 (page 7).

1.3.2.2. Vertical Restrictions

The vertical location (V) is limited by the floor surface and the upper limit of vertical reach for lifting (i.e.,70 inches or 175 cm). The vertical location should be measured at the origin and the destination of the lift to determine the travel distance (D).

1.3.2.3. Vertical Multiplier

To determine the Vertical Multiplier (VM), the absolute value or deviation of V from an optimum height of 30 inches (75 cm) is calculated. A height of 30 inches above floor level is considered "knuckle height" for a worker of average height (66 inches or 165 cm). The Vertical Multiplier (VM) is $(1-(.0075\,|V-30|))$ for V measured in inches, and VM is $(1-(.003\,|V-75|))$, for V measured in centimeters.

When V is at 30 inches (75 cm), the vertical multiplier (VM) is 1.0. The value of VM decreases linearly with an increase or decrease in height from this position. At floor level, VM is 0.78, and at 70 inches (175 cm) height VM is 0.7. If V is greater than 70 inches, then VM = 0. The VM value can be computed directly or determined from Table 2.

Table 2
Vertical Multiplier

V	VM	V	VM
in		cm	
0	.78	0	.78
5	.81	10	.81
10	.85	20	.84
15	.89	30	.87
20	.93	40	.90
25	.96	50	.93
30	1.00	60	.96
35	.96	70	.99
40	.93	80	.99
45	.89	90	.96
50	.85	100	.93
55	.81	110	.90
60	.78	120	.87
65	.74	130	.84
70	.70	140	.81
>70	.00	150	.78
		160	.75
		170	.72
		175	.70
		>175	.00

1.3.3. Distance Component

1.3.3.1. Definition and Measurement

The **Vertical Travel Distance** variable (D) is defined as the vertical travel distance of the hands between the origin and destination of the lift. For lifting, D can be computed by subtracting the vertical location (V) at the origin of the lift from the corresponding V at the destination of the lift (i.e., D is equal to V at the destination minus V at the origin). For a lowering task, D is equal to V at the origin minus V at the destination.

1.3.3.2 Distance Restrictions

The variable (D) is assumed to be at least 10 inches (25 cm), and no greater than 70 inches [175 cm]. If the vertical travel distance is less than 10 inches (25 cm), then D should be set to the minimum distance of 10 inches (25 cm).

1.3.3.3 Distance Multiplier

The Distance Multiplier (DM) is (.82 + (1.8/D)) for D measured in inches, and DM is (.82 + (4.5/D)) for D measured in centimeters. For D less than 10 inches (25 cm) D is assumed to be 10 inches (25 cm), and DM is 1.0. The Distance Multiplier, therefore, decreases gradually with an increase in travel distance. The DM is 1.0 when D is set at 10 inches, (25 cm); DM is 0.85 when D = 70 inches (175 cm). Thus, DM ranges from 1.0 to 0.85 as the D varies from 0 inches (0 cm) to 70 inches (175 cm). The DM value can be computed directly or determined from Table 3.

1.3.4. Asymmetry Component

1.3.4.1. Definition and Measurement

Asymmetry refers to a lift that begins or ends outside the mid-sagittal plane as shown in Figure 2 on page 8. In general, asymmetric lifting should be avoided. If asymmetric lifting cannot be avoided, however, the recommended weight limits are significantly less than those limits used for symmetrical lifting.[5]

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[5] It may not always be clear if asymmetry is an intrinsic element of the task or just a personal characteristic of the worker's lifting style. Regardless of the reason for the asymmetry, any observed asymmetric lifting should be considered an intrinsic element of the job design and should be considered in the assessment and subsequent redesign. Moreover, the design of the task should not rely on worker compliance, but rather the design should discourage or eliminate the need for asymmetric lifting.

Table 3
Distance Multiplier

D	DM	D	DM
in		cm	
≤10	1.00	≤25	1.00
15	.94	40	.93
20	.91	55	.90
25	.89	70	.88
30	.88	85	.87
35	.87	100	.87
40	.87	115	.86
45	.86	130	.86
50	.86	145	.85
55	.85	160	.85
60	.85	175	.85
70	.85	>175	.00
>70	.00		

An asymmetric lift may be required under the following task or workplace conditions:

1. The origin and destination of the lift are oriented at an angle to each another.

2. The lifting motion is across the body, such as occurs in swinging bags or boxes from one location to another.

3. The lifting is done to maintain body balance in obstructed workplaces, on rough terrain, or on littered floors.

4. Productivity standards require reduced time per lift.

The asymmetric angle (A), which is depicted graphically in Figure 2, is operationally 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 ankle bones 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). Note: The asymmetry angle is not defined by foot position or the angle of torso twist, but by the location of the load relative to the worker's mid-sagittal plane.

In many cases of asymmetric lifting, the worker will pivot or use a step turn to complete the lift. Since this may vary significantly between workers and between lifts, we have assumed that 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) must always be measured at the origin of the lift. If significant control is required at the destination, however, then angle A should be measured at both the origin and the destination of the lift.

1.3.4.2. Asymmetry Restrictions

The angle A is limited to the range from 0° to 135°. If $A > 135°$, then AM is set equal to zero, which results in a RWL of zero, or no load.

1.3.4.3. Asymmetric Multiplier

The Asymmetric Multiplier (AM) is $1-(.0032A)$. The AM has a maximum value of 1.0 when the load is lifted directly in front of the body. The AM decreases linearly as the angle of asymmetry (A) increases. The range is from a value of 0.57 at 135° of asymmetry to a value of 1.0 at 0° of asymmetry (i.e., symmetric lift).

If A is greater than 135°, then AM = 0, and the load is zero. The AM value can be computed directly or determined from Table 4.

Table 4
Asymmetric Multiplier

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

1.3.5. Frequency Component

1.3.5.1 Definition and Measurement

The frequency multiplier is defined by (a) the number of lifts per minute (frequency), (b) the amount of time engaged in the lifting activity (duration), and (c) the vertical height of the lift from the floor. Lifting frequency (F) refers to the average number of lifts made per minute, as measured over a 15-minute period. Because of the potential variation in work patterns, analysts may have difficulty obtaining an accurate or representative 15-minute work sample for computing the lifting frequency (F). If significant variation exists in the frequency of lifting over the course of the day, analysts should employ standard work sampling techniques to obtain a representative work sample for determining the number of lifts per minute. For those jobs where the frequency varies from session to session, each session should be analyzed separately, but the overall work pattern must still be considered. For more information, most standard industrial engineering or ergonomics texts provide guidance for establishing a representative job sampling strategy (e.g., Eastman Kodak Company, 1986).

1.3.5.2 Lifting Duration

Lifting duration is classified into three categories--short-duration, moderate-duration and long-duration. These categories are based on the pattern of continuous ***work-time*** and ***recovery-time*** (i.e., light work) periods. A continuous work-time period is defined as a period of uninterrupted work. Recovery-time is defined as the duration of light work activity following a period of continuous lifting. Examples of light work include activities such as sitting at a desk or table, monitoring operations, light assembly work, etc.

1. **Short-duration** defines lifting tasks that have a work duration of ***one hour or less***, followed by a recovery time equal to 1.2 times the work time [i.e., at least a 1.2 recovery-time to work-time ratio (RT/WT)].

For example, to be classified as short-duration, a 45-minute lifting job must be followed by at least a 54-minute recovery period prior to initiating a subsequent lifting session. If the required recovery time is not met for a job of one hour or less, and a subsequent lifting session is required, then the total lifting time must be combined to correctly determine the duration category. Moreover, if the recovery period does not meet the time requirement, it is disregarded for purposes of determining the appropriate duration category.

As another example, assume a worker lifts continuously for 30 minutes, then performs a light work task for 10 minutes, and then lifts for an additional 45-minute period. In this case, the recovery time between lifting sessions (10 minutes) is less than 1.2 times the initial 30-minute work time (36 minutes). Thus, the two work times (30 minutes and 45 minutes) must be added together to determine the duration. Since the total work time (75 minutes) exceeds 1 hour, the job is classified as moderate-duration. On the other hand, if the recovery period between lifting sessions was increased to 36 minutes, then the short-duration category would apply, which would result in a larger FM value.

2. **Moderate-duration** defines lifting tasks that have a duration of ***more than one hour, but not more than two hours***, followed by a recovery period of at least 0.3 times the work time [i.e., at least a 0.3 recovery-time to work-time ratio (RT/WT)].

For example, if a worker continuously lifts for 2 hours, then a recovery period of at least 36 minutes would be required before initiating a subsequent lifting session. If the recovery time requirement is not met, and a subsequent lifting session is required, then the total work time must be added together. If the total work time exceeds 2 hours, then the job must be classified as a long-duration lifting task.

3. **Long-duration** defines lifting tasks that have a duration of ***between two and eight hours***, with standard industrial rest allowances (e.g., morning, lunch, and afternoon rest breaks).

Note: No weight limits are provided for more than eight hours of work.

The difference in the required RT/WT ratio for the short-duration category (less than 1 hour), which is 1.2, and the moderate-duration category (1-2 hours), which is .3, is due to the difference in the magnitudes of the frequency multiplier values associated with each of the duration categories. Since the moderate-duration category results in larger reductions in the RWL than the short-duration category, there is less need for a recovery period between sessions than for the short duration category. In other words, the short duration category would result in higher weight limits than the moderate duration category, so larger recovery periods would be needed.

1.3.5.3. Frequency Restrictions

Lifting frequency (F) for repetitive lifting may range from 0.2 lifts/min to a maximum frequency that is dependent on the vertical location of the object (V) and the duration of lifting (Table 5). Lifting above the maximum frequency results in a RWL of 0.0. (Except for the special case of discontinuous lifting discussed above, where the maximum frequency is 15 lifts/minute.)

1.3.5.4. Frequency Multiplier

The FM value depends upon the average number of lifts/min (F), the vertical location (V) of the hands at the origin, and the duration of continuous lifting. For lifting tasks with a frequency less than .2 lifts per minute, set the frequency equal to .2 lifts/minute. For infrequent lifting (i.e., $F < .1$ lift/minute), however, the recovery period will usually be sufficient to use the 1-hour duration category. The FM value is determined from Table 5.

Table 5
Frequency Multiplier Table (FM)

Frequency Lifts/min (F) ‡	Work Duration					
	≤ 1 Hour		>1 but ≤ 2 Hours		>2 but ≤ 8 Hours	
	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

†Values of V are in inches. ‡For lifting less frequently than once per 5 minutes, set F = .2 lifts/minute.

1.3.5.5. Special Frequency Adjustment Procedure

A ***special procedure*** has been developed for determining the appropriate lifting frequency (F) for certain repetitive lifting tasks in which workers do not lift continuously during the 15 minute sampling period. This occurs when the work pattern is such that the worker lifts repetitively for a short time and then performs light work for a short time before starting another cycle. As long as the actual lifting frequency does not exceed 15 lifts per minute, the lifting frequency (F) may be determined for tasks such as this as follows:

1. Compute the total number of lifts performed for the 15 minute period (i.e., lift rate times work time).

2. Divide the total number of lifts by 15.

3. Use the resulting value as the frequency (F) to determine the frequency multiplier (FM) from Table 5.

For example, if the work pattern for a job consists of a series of cyclic sessions requiring 8 minutes of lifting followed by 7 minutes of light work, and the lifting rate during the work sessions is 10 lifts per minute, then the frequency rate (F) that is used to determine the frequency multiplier for this job is equal to (10 x 8)/15 or 5.33 lifts/minute. If the worker lifted continuously for more than 15 minutes, however, then the actual lifting frequency (10 lifts per minute) would be used.

When using this special procedure, the duration category is based on the magnitude of the recovery periods ***between*** work sessions, not ***within*** work sessions. In other words, if the work pattern is intermittent and the special procedure applies, then the intermittent recovery periods that occur during the 15-minute sampling period are ***not*** considered as recovery periods for purposes of determining the duration category. For example, if the work pattern for a manual lifting job was composed of repetitive cycles consisting of 1 minute of continuous lifting at a rate of 10 lifts/minute, followed by 2 minutes of recovery, the correct procedure would be to adjust the frequency according to the special procedure [i.e., F = (10 lifts/minute x 5 minutes)/15 minutes = 50/15 = 3.4 lifts/minute.] The 2-minute recovery periods would not count towards the WT/RT ratio, however, and additional recovery periods would have to be provided as described above.

1.3.6. Coupling Component

1.3.6.1. Definition & Measurement

The nature of the hand-to-object coupling or gripping method can affect not only the maximum force a worker can or must exert on the object, but also the vertical location of the hands during the lift. A ***good*** coupling will reduce the maximum grasp forces required and increase the acceptable weight for lifting, while a ***poor*** coupling will generally require higher maximum grasp forces and decrease the acceptable weight for lifting.

The effectiveness of the coupling is not static, but may vary with the distance of the object from the ground, so that a good coupling could become a poor coupling during a single lift. The entire range of the lift should be considered when classifying hand-to-object couplings, with classification based on overall effectiveness. The analyst must classify the coupling as good, fair, or poor. The three categories are defined in Table 6. If there is any doubt about classifying a particular coupling design, the more stressful classification should be selected.

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 or 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 .75 - 1.5 inches (1.9 to 3.8 cm) diameter, ≥ 4.5 inches (11.5 cm) length, 2 inches (5 cm) clearance, cylindrical shape, and a smooth, non-slip surface.

2. An optimal hand-hold cut-out has the following approximate characteristics: ≥ 1.5 inch (3.8 cm) height, 4.5 inch (11.5 cm) length, semi-oval shape, ≥ 2 inch (5 cm) clearance, smooth non-slip surface, and ≥ 0.25 inches (0.60 cm) container thickness (e.g., double thickness cardboard).

3. An optimal container design has ≤ 16 inches (40 cm) frontal length, ≤ 12 inches (30 cm) height, and a smooth non-slip surface.

4. A worker should be capable of clamping the fingers at nearly 90° 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 (40 cm), height > 12 inches (30 cm), rough or slippery surfaces, sharp edges, asymmetric center of mass, unstable contents, or requires the use 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 or awkward postures, and the grip should not require excessive force.

1.3.6.2. Coupling Multiplier

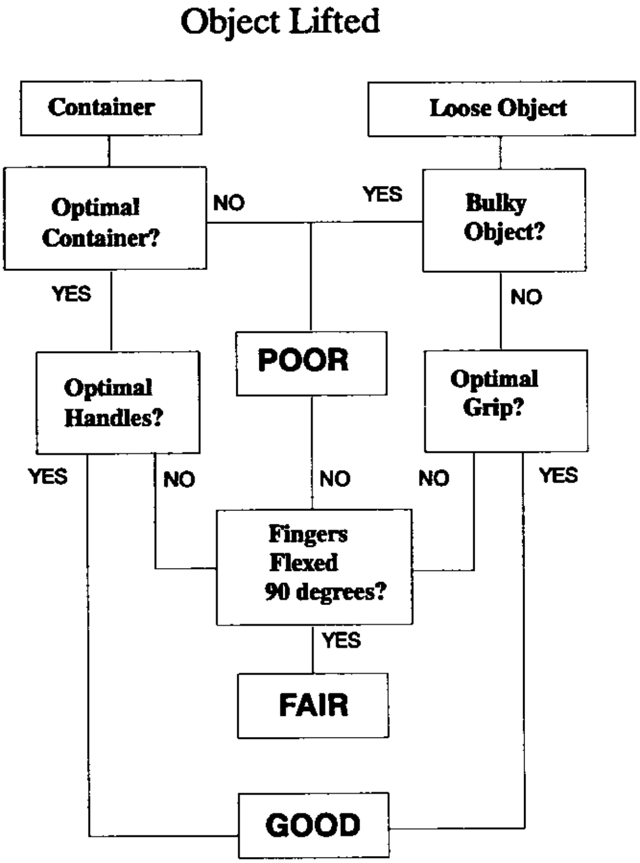
Based on the coupling classification and vertical location of the lift, the Coupling Multiplier (CM) is determined from Table 7.

Table 7
Coupling Multiplier

Coupling Type	Coupling Multiplier	
	V< 30 inches (75 cm)	V ≥ 30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

The following decision tree may be helpful in classifying the hand-to-object coupling.

Decision Tree for Coupling Quality



1.4. The Lifting Index (LI)

As defined earlier, the Lifting Index (LI) provides a relative estimate of the physical stress associated with a manual lifting job.

$$\text{LI} = \frac{\textbf{Load Weight}}{\textbf{Recommended Weight Limit}} = \frac{\textbf{L}}{\textbf{RWL}}$$

Where **Load Weight (L)** = weight of the object lifted (lbs or kg).

1.4.1. Using the RWL and LI to Guide Ergonomic Design

The recommended weight limit (RWL) and lifting index (LI) can be used to guide ergonomic design in several ways:

(1) The individual multipliers can be used to identify specific job-related problems. The relative magnitude of each multiplier indicates the relative contribution of each task factor (e.g., horizontal, vertical, frequency, etc.)

(2) The RWL can be used to guide the redesign of existing manual lifting jobs or to design new manual lifting jobs. For example, if the task variables are fixed, then the maximum weight of the load could be selected so as not to exceed the RWL; if the weight is fixed, then the task variables could be optimized so as not to exceed the RWL.

(3) The LI can be used to estimate the relative magnitude of physical stress for a task or job. The greater the LI, the smaller the fraction of workers capable of safely sustaining the level of activity. Thus, two or more job designs could be compared.

(4) The LI can be used to prioritize ergonomic redesign. For example, a series of suspected hazardous jobs could be rank ordered according to the LI and a control strategy could be developed according to the rank ordering (i.e., jobs with lifting

indices above 1.0 or higher would benefit the most from redesign).

1.4.2. Rationale and Limitations for LI

The NIOSH Recommended Weight Limit (RWL) equation and Lifting Index (LI) are based on the concept that the risk of lifting-related low back pain increases as the demands of the lifting task increase. In other words, as the magnitude of the LI increases, (1) the level of the risk for a given worker would be increased, and (2) a greater percentage of the workforce is likely to be at risk for developing lifting-related low back pain. The shape of the risk function, however, is not known. Without additional data showing the relationship between low back pain and the LI, it is impossible to predict the magnitude of the risk for a given individual or the exact percent of the work population who would be at an elevated risk for low back pain.

To gain a better understanding of the rationale for the development of the RWL and LI, consult the paper entitled *Revised NIOSH Equation for the Design and Evaluation of Manual Lifting Tasks* by Waters, Putz-Anderson, Garg, and Fine (1993) (Appendix I). This article provides a discussion of the criteria underlying the lifting equation and of the individual multipliers. This article also identifies both the assumptions and uncertainties in the scientific studies that associate manual lifting and low back injuries.

1.4.3. Job-Related Intervention Strategy

The lifting index may be used to identify potentially hazardous lifting jobs or to compare the relative severity of two jobs for the purpose of evaluating and redesigning them. 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 (Waters *et al.*, 1993). Hence, the goal should be to design all lifting jobs to achieve a LI of 1.0 or less.

Some experts believe, however, that worker selection criteria may be used to identify workers who can perform potentially stressful lifting tasks (i.e., lifting tasks that would exceed a LI of 1.0) without significantly increasing their risk of work-related injury (Chaffin and Anderson, 1984; Ayoub and Mital, 1989). 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 a work-related injury when performing highly stressful lifting tasks (i.e., lifting tasks that would exceed a LI of 3.0). Also, ***informal*** or ***natural*** selection of workers may occur in many jobs that require repetitive lifting tasks. According to some experts, this may result in a unique workforce that may be able to work above a lifting index of 1.0, at least in theory, without substantially increasing their risk of low back injuries above the baseline rate of injury.