

CHAPTER 13

ASSESSMENT OF MANUAL LIFTING—THE NIOSH APPROACH

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THE BODY OF WORK

Historically, the National Institute for Occupational Safety and Health (NIOSH) has recognized and addressed the problem of work-related back injuries and published the *Work Practices Guide for Manual Lifting (WPG)* in 1981 (NIOSH 1981). The *WPG* contains a summary of the lifting-related literature up to 1981, analytical procedures, 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 with the *action limit (AL)*, a term that denoted the recommended weight derived from the lifting equation.

In 1985, NIOSH convened an ad hoc committee of experts who reviewed the current literature on lifting, including the NIOSH *WPG*. The literature review was summarized in a document containing updated information on the physiological, biomechanical, psychophysical, and epidemiological aspects of manual lifting (NIOSH 1991). 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 (Waters et al. 1994). Subsequently, NIOSH staff developed documentation for the equa-

tion 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 1981).

The rationale and criteria for developing the revised NIOSH lifting equation are provided in a journal article by Waters et al. (1993). The article provides a better understanding of the data and decisions made in formulating the revised equation. It offers an explanation on selecting the biomechanical, physiological, and psychophysical criteria, and describes the derivation of each component of the revised lifting equation. However, for those individuals primarily concerned with applying the revised lifting equation, this chapter provides a more complete description of the method and limitations.

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. 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 solely on a single task factor or 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. Examples of other approaches are described elsewhere (ASPH/NIOSH 1986). Moreover, lifting is only one cause of work-related low-back pain and disability. Other causes that 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 also may be particularly important in influencing the transition of acute low-back pain to chronic disabling pain (see Chapter 12, "Manual Material Handling").

RECOMMENDED WEIGHT LIMIT (RWL)

The principal product of the revised NIOSH lifting equation is the *recommended weight limit (RWL)*. 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 (up to eight hours) without an increased risk of developing lifting-related low-back pain (LBP). "Healthy workers" are those who are

free of adverse health conditions that would increase their risk of musculoskeletal injury.

The concept behind the revised NIOSH lifting equation is to start with a recommended weight that is considered safe for an "ideal" lift (load constant equal to 51 lb [23 kg]) and then reduce the weight as the task becomes more stressful (the task-related factors become less favorable). The precise formulation of the revised lifting equation for calculating the RWL is based on a multiplicative model that provides a weighting (multiplier) for each of six task variables:

1. Horizontal distance of the load from the worker (H) (Table 13-1).
2. Vertical height of the lift (V) (Table 13-2).
3. Vertical displacement during the lift (D) (Table 13-3).
4. Angle of asymmetry (A) (Table 13-4).
5. Frequency (F) and duration of lifting (Table 13-5).
6. Quality of the hand-to-object coupling (C) (Tables 13-6 and 13-7).

Table 13-1. Horizontal multiplier

Horizontal distance in.	Horizontal multiplier	Horizontal distance cm	Horizontal multiplier
≤10	1.00	≤25	1.00
11	0.91	28	0.89
12	0.83	30	0.83
13	0.77	32	0.78
14	0.71	34	0.74
15	0.67	36	0.69
16	0.63	38	0.66
17	0.59	40	0.63
18	0.56	42	0.60
19	0.53	44	0.57
20	0.50	46	0.54
21	0.48	48	0.52
22	0.46	50	0.50
23	0.44	52	0.48
24	0.42	54	0.46
25	0.40	56	0.45
>25	0.00	58	0.43
		60	0.42
		63	0.40
		>63	0.00

Table 13-2. Vertical multiplier

Vertical distance in.	Vertical multiplier	Vertical distance cm	Vertical multiplier
0	0.78	0	0.78
5	0.81	10	0.81
10	0.85	20	0.84
15	0.89	30	0.87
20	0.93	40	0.90
25	0.96	50	0.93
30	1.00	60	0.96
35	0.96	70	0.99
40	0.93	80	0.99
45	0.89	90	0.96
50	0.85	100	0.93
55	0.81	110	0.90
60	0.78	120	0.87
65	0.74	130	0.84
70	0.70	140	0.81
>70	0.00	150	0.78
		160	0.75
		170	0.72
		175	0.70
		>175	0.00

Table 13-3. Distance multiplier

Distance in.	Distance multiplier	Distance cm	Distance multiplier
≤10	1.00	≤25	1.00
15	0.94	40	0.93
20	0.91	55	0.90
25	0.89	70	0.88
30	0.88	85	0.87
35	0.87	100	0.87
40	0.87	115	0.86
45	0.86	130	0.86
50	0.86	145	0.85
55	0.85	160	0.85
60	0.85	175	0.85
70	0.85	>175	0.00
>70	0.00		

Table 13-4. Asymmetric multiplier

Angle of asymmetry A (°)	Asymmetric multiplier
0	1.000
15	0.95
30	0.90
45	0.86
60	0.81
75	0.76
90	0.71
105	0.66
120	0.62
135	0.57
>135	0.00

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. For example, as the horizontal distance between the load and the worker increases from 10 in. (25 cm), the recommended weight limit for that task would be reduced from the ideal starting weight.

Table 13-5. Frequency multiplier (FM)

Frequency (F)* lifts/min	Work duration					
	≤1 hr		>1 but ≤2 hr		>2 but ≤8 hr	
	V** < 30	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤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	0.94	0.94	0.88	0.88	0.75	0.75
2.0	0.91	0.91	0.84	0.84	0.65	0.65
3.0	0.88	0.88	0.79	0.79	0.55	0.55
4.0	0.84	0.84	0.72	0.72	0.45	0.45
5.0	0.80	0.80	0.60	0.60	0.35	0.35
6.0	0.75	0.75	0.50	0.50	0.27	0.27
7.0	0.70	0.70	0.42	0.42	0.22	0.22
8.0	0.60	0.60	0.35	0.35	0.18	0.18
9.0	0.52	0.52	0.30	0.30	0.00	0.15
10.0	0.45	0.45	0.26	0.26	0.00	0.13
11.0	0.41	0.41	0.00	0.23	0.00	0.00
12.0	0.37	0.37	0.00	0.21	0.00	0.00
13.0	0.00	0.34	0.00	0.00	0.00	0.00
14.0	0.00	0.31	0.00	0.00	0.00	0.00
15.0	0.00	0.28	0.00	0.00	0.00	0.00
>15.0	0.00	0.00	0.00	0.00	0.00	0.00

* For lifting < once per 5 min, set F = 0.2 lifts/min
 ** Values of V are in inches

Table 13-6. Hand-to-container coupling classification

Good	Fair	Poor
<p>1. For containers of optimal design, such as some boxes, crates, etc., a "good" hand-to-object coupling would be defined as handles or handhold cutouts of optimal design (see notes 1 to 3 below).</p>	<p>1. For containers of optimal design, a "fair" hand-to-object coupling would be defined as handles or handhold cutouts of less than optimal design (see notes 1 to 4 below).</p>	<p>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).</p>
<p>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).</p>	<p>2. For containers of optimal design with no handles or handhold cutouts 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° (see note 4 below).</p>	<p>2. Lifting nonrigid bags (i.e., bags that sag in the middle).</p>
<ul style="list-style-type: none"> • An optimal handle design has 0.75 to 1.5 in. (1.9 to 3.8 cm) diameter, \geq 4.5 in. (11.4 cm) length, 2 in. (5 cm) clearance, cylindrical shape, and a smooth, nonslip surface. • An optimal handhold cutout has these approximate characteristics: \geq 1.5 in. (3.8 cm) height, 4.5 in. (11.4 cm) length, semi-oval shape, \geq 2 in. (5 cm) clearance, smooth nonslip surface, and \geq 0.25 in. (0.64 cm) container thickness (e.g., double thickness cardboard). • An optimal container design has \leq 16 in. (41 cm) frontal length, \leq 12 in. (30 cm) height, and a smooth nonslip surface. • 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. • A container is considered less than optimal if it has a frontal length $>$ 16 in. (40 cm), height $>$ 12 in. (30 cm), rough or slippery surfaces, sharp edges, asymmetric center of mass, unstable contents, or requires the use of gloves. • 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. 		

Table 13-7. Coupling multiplier

Coupling type	Coupling multiplier	
	V < 29.5 in. (75 cm)	V ≥ 29.5 in. (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

The *RWL* is defined as

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

where:

	<u>U.S. Customary</u>	<u>Metric</u>
<i>LC</i> = load constant	= 51 lb	23 kg
<i>HM</i> = horizontal multiplier	= (10/ <i>H</i>)	(25/ <i>H</i>)
<i>VM</i> = vertical multiplier	= 1 - (.0075 <i>V</i> -30)	1 - (.003 <i>V</i> -75)
<i>DM</i> = distance multiplier	= 0.82 + (1.8/ <i>D</i>)	0.82 + (4.5/ <i>D</i>)
<i>AM</i> = asymmetric multiplier	= 1 - (0.0032 <i>A</i>)	1 - (0.0032 <i>A</i>)
<i>FM</i> = frequency multiplier	= from Table 13-5	from Table 13-5
<i>CM</i> = coupling multiplier	= from Table 13-7	from Table 13-7

The term *task variables* refers to the task-related measurements used as input data for the formula (*H*, *V*, *D*, *A*, *F*, and *C*), whereas, the term *multipliers* refers to the reduction coefficients in the equation (*HM*, *VM*, *DM*, *AM*, *FM*, and *CM*).

MEASUREMENT REQUIREMENTS

The following list briefly describes the measurements required to use the revised NIOSH lifting equation. Details for each variable are presented later in this chapter.

H = Horizontal location of the hands from the midpoint between the inner ankle bones. Measure at the origin and destination of the lift (in. or cm).

V = Vertical location of the hands from the floor. Measure at the origin and destination of the lift (in. or cm).

D = Vertical travel distance between the origin and the destination of the lift (in. or cm).

A = Angle of asymmetry or angular displacement of the load from the worker's sagittal plane. Measure at the origin and destination of the lift (°).

F = Average frequency rate of lifting, measured in lifts per minute. Duration is defined to be less than 1 hour; 1-2 hours; or 2-8 hours, assuming appropriate recovery allowances (see Table 13-5).

C = Quality of hand-to-object coupling (interface between the worker and the load lifted). The quality of the coupling is classified as good, fair, or poor depending upon the type and location of the coupling, the physical characteristics of the load, and the vertical height of the lift.

LIFTING INDEX (LI)

The *lifting index* (LI) offers 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 between the weight of the load lifted and the recommended weight limit. LI is defined by the equation

$$LI = \frac{L}{RWL}$$

where:

LI = lifting index

L = load weight of the object lifted (lb or kg)

RWL = recommended weight limit

MISCELLANEOUS TERMS

Lifting task. 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 midpoint between the ankles, in inches or centimeters (measure at the origin and destination of lift, see Figure 13-1).

Vertical location (V). Distance of the hands above the floor, in inches or centimeters (measure at the origin and destination of lift, see Figure 13-1).

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.

Angle of asymmetry (A). Angular measure of how far the *object* is displaced from the front (midsagittal plane) of the worker's body at the beginning or end of the lift, in degrees (measure at the origin and destination of lift, see Figure 13-2). The asymmetry angle is defined by the location of the load relative to the worker's midsagittal plane, as defined by the neutral body posture, rather than the position of the feet or extent of body twist.

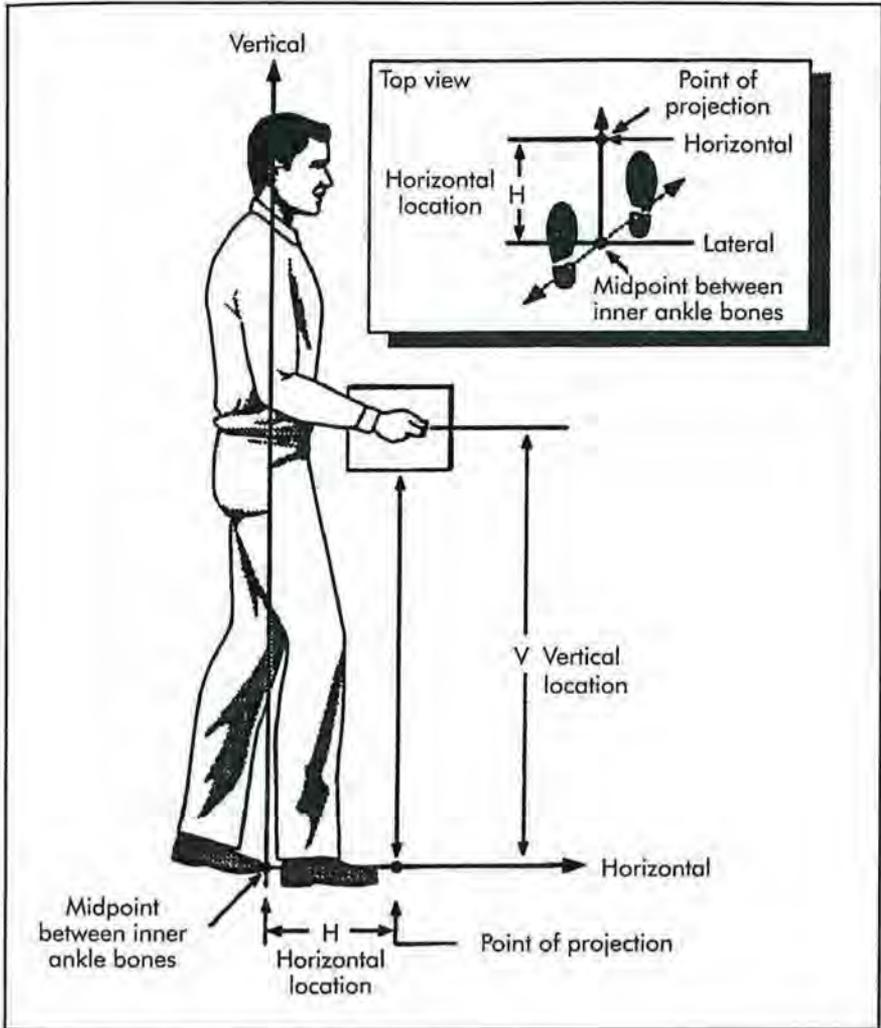


Figure 13-1 Graphic representation of hand location.

Neutral body position. Position of the body where the hands are directly in front of it and there is minimal twisting of the legs, torso, or shoulders.

Frequency of lifting (F). Average number of lifts per minute over a 15-minute period.

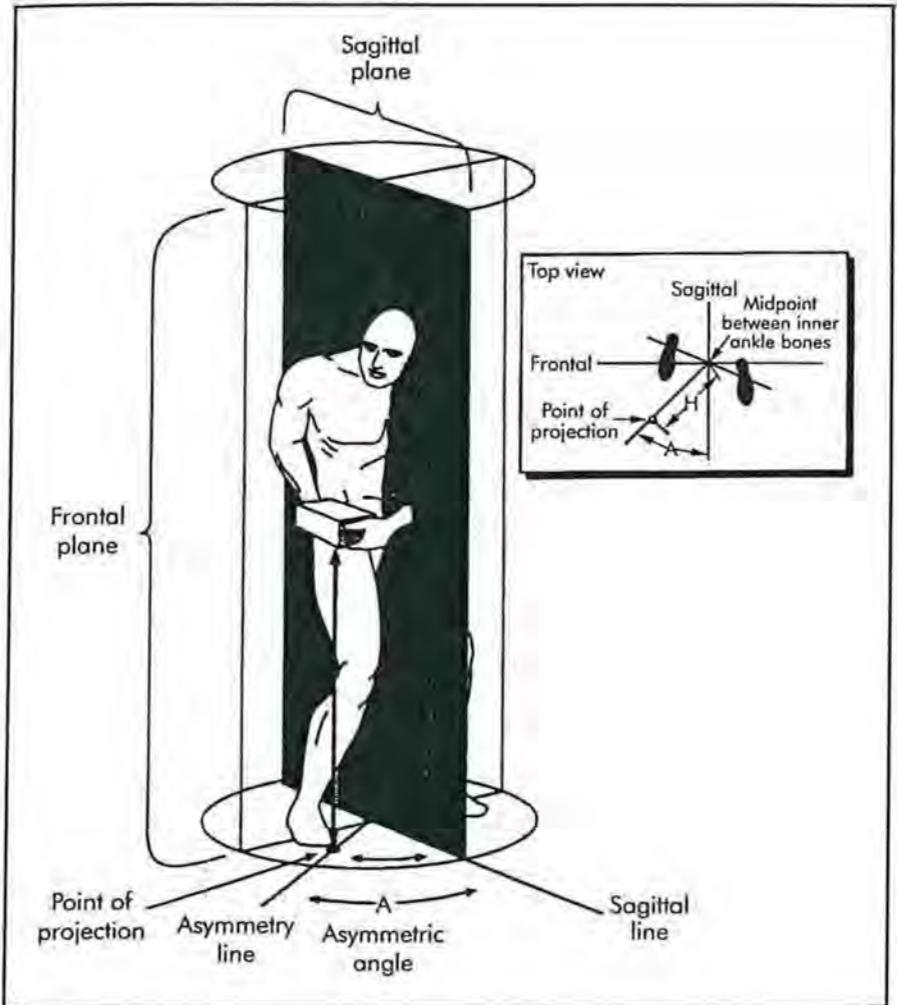


Figure 13-2 Graphic representation of angle of asymmetry (A).

Duration of lifting. 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 (handle, cut-out, or grip). Coupling quality is classified as good, fair, or poor.

Significant control. A condition requiring precision placement of the load at the destination of the lift. This is usually the case when the worker has to re-grasp the load near the destination of the lift, the worker has to momentarily hold the object at the destination, or when the worker has to carefully position or guide the load at the destination.

EQUATION 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. The lifting equation was designed to meet specific lifting-related criteria that encompass biomechanical, physiological, and psychophysical assumptions and data used to develop the equation. 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 where the application of the lifting equation could either underestimate or overestimate the extent of physical stress associated with a particular work-related activity. Each of the following task limitations also highlights topics in need of further research to extend the application of the lifting equation to a greater range of real-world lifting tasks.

The revised NIOSH lifting equation does not apply if the operator performs lifting or lowering:

- With one hand;
- For over 8 hours;
- While seated or kneeling;
- In a restricted work space;
- Of objects considered unstable;
- While carrying, pushing, or pulling;
- With wheelbarrows or shovels;
- With high-speed motion (faster than 30 in./second [76 cm/second]);
- With unreasonable foot/floor coupling (< 0.4 coefficient of friction between the sole and the floor); or
- In an unfavorable environment (temperature significantly outside the 66-79° F [19-26° C] range; relative humidity outside the 35-50% range).

HORIZONTAL COMPONENT

Definition and Measurement

Horizontal location (H) is measured from the midpoint of the line joining the inner ankle bones to a point projected on the floor directly below the midpoint of the hand grasps (load center), as defined by the large middle knuckle of the hand (Figure 13-1). Typically, the worker's feet are not aligned with the midsagittal plane, as shown in Figure 13-1, but may be rotated inward or outward. If this is the case, then the midsagittal plane is defined by the worker's neutral body posture as defined above. If significant control is required at the destination (precision placement), then H should be measured at both the origin and destination of the lift.

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

U.S. Customary (all distances in inches)

$$H = 8 + W/2 \text{ for } V \geq 10 \text{ in.}$$

$$H = 10 + W/2 \text{ for } V < 10 \text{ in.}$$

Metric (all distances in centimeters)

$$H = 20 + W/2 \text{ for } V \geq 25 \text{ cm}$$

$$H = 25 + W/2 \text{ for } V < 25 \text{ cm}$$

where:

H = horizontal distance

W = width of the container in the sagittal plane

V = vertical location of the hands from the floor

Horizontal Restrictions

If the horizontal distance is less than 10 in. (25 cm), then H is set to 10 in. (25 cm). Although objects can be carried or held closer than 10 in. (25 cm) from the ankles, most objects that are closer cannot be lifted without encountering interference from the abdomen or hyperextending the shoulders. Although 25 in. (64 cm) was chosen as the maximum value for H , it is probably too great a distance for shorter workers, particularly when lifting asymmetrically. Furthermore, objects at a distance of more than 25 in. (64 cm) from the ankles normally cannot be lifted vertically without some loss of balance.

Horizontal Multiplier

The horizontal multiplier (HM) is $10/H$ for H measured in inches and $25/H$ for H measured in centimeters. If H is less than or equal to 10 in. (25 cm), 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 in. (64 cm). If H is greater than 25 in. (64 cm), then $HM = 0$. The HM value can be computed directly or determined from Table 13-1.

VERTICAL COMPONENT

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 was illustrated in Figure 13-1.

Vertical Restrictions

Vertical location (V) is limited by the floor surface and upper limit of vertical reach for lifting (70 in. [178 cm]). The vertical location should be measured at the origin and destination of the lift.

Vertical Multiplier

To determine the vertical multiplier (VM), the absolute value or deviation of V from an optimum height of 30 in. (76 cm) is calculated. A height of 30 in. (76 cm) above floor level is considered "knuckle height" for a worker of average height (66 in. [168 cm]). The vertical multiplier (VM) is $(1 - (0.0075 |V - 30|))$ for V measured in inches, and VM is $(1 - (0.003 |V - 75|))$, for V measured in centimeters.

When V is at 30 in. (76 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, $VM = 0.78$, and at 70 in. (178 cm) height, $VM = 0.7$. If V is greater than 70 in. (178 cm), then $VM = 0$. The VM value can be computed directly or determined from Table 13-2.

DISTANCE COMPONENT

Definition and Measurement

The 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 (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.

Distance Restrictions

The distance variable (D) is assumed to be at least 10 in. (25 cm) and no greater than 70 in. (178 cm). If the vertical travel distance is less than 10 in. (25 cm), then D should be set to the minimum distance of 10 in. (25 cm).

Distance Multiplier

The distance multiplier (DM) is $(0.82 + (1.8/D))$ for D measured in inches and $(0.82 + (4.5/D))$ for D measured in centimeters. For D less than 10 in. (25 cm), D is assumed to be 10 in. (25 cm), and DM is 1.0. The distance multiplier, therefore, decreases gradually with an increase in travel distance. The $DM = 1.0$ when D is set at 10 in. (25 cm); $DM = 0.85$ when D is 70 in. (178 cm). Thus, DM ranges from 1.0-0.85 as the D varies from 0-70 in. (0-178 cm). The DM value can be computed directly or determined from Table 13-3.

ASYMMETRY COMPONENT

Definition and Measurement

Asymmetry refers to a lift that begins or ends outside the midsagittal plane (see Figure 13-2). In general, asymmetric lifting should be avoided. If it cannot be avoided, however, the recommended weight limits are significantly less than those used for symmetrical lifting.*

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

- The origin and destination of the lift are oriented at an angle to each other;
- The lifting motion is across the body, such as in swinging bags or boxes from one location to another;
- The lifting is done to maintain body balance in obstructed workplaces, on rough terrain, or on littered floors; and
- Productivity standards require reduced time per lift.

The asymmetric angle (A), depicted in Figure 13-2, is operationally defined as the angle between the asymmetry line and the mid-

*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.

sagittal line. The *asymmetry line* is defined as the line that joins the midpoint between the inner ankle bones and the point projected on the floor directly below the midpoint of the hand grasps, as defined by the large middle knuckle. The *sagittal line* is defined as the line passing through the midpoint between the inner ankle bones and lying in the midsagittal plane, as defined by the neutral body position (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 midsagittal plane.

In many cases of asymmetric lifting, the worker will pivot or use a step turn to complete the lift. Because 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.

Asymmetry Restrictions

Angle A is limited to a range of 0-135°. If $A > 135^\circ$, then AM is set to equal zero, which results in a RWL of zero, or no load.

Asymmetric Multiplier

The asymmetric multiplier (AM) is $1 - (0.0032A)$. AM has a maximum value of 1.0 when the load is lifted directly in front of the body and 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 (symmetric lift). If A is greater than 135°, then $AM = 0$, and the $RWL = 0.0$. The AM value can be computed directly or determined from Table 13-4.

FREQUENCY COMPONENT

Definition and Measurement

The frequency multiplier is defined by 1) number of lifts per minute (frequency), 2) amount of time engaged in the lifting activity (duration), and 3) 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 F . If significant variation exists in the frequency of lift-

ing 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 (Eastman Kodak 1986).

Lifting Duration

Lifting duration is classified into three categories based on the pattern of continuous work time and recovery time (light work) periods. A continuous *work time* (WT) period is defined as a period of uninterrupted work. *Recovery time* (RT) 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, and light assembly work. The three categories are short duration, moderate duration, and long duration.

Short duration. Short duration lifting tasks are those that have a work duration of one hour or less, followed by a recovery time equal to 1.2 times the work time (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 one 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, resulting in a larger FM value.

Moderate duration. Moderate duration lifting tasks are those that have a duration of more than 1 hour, but not more than 2 hours,

followed by a recovery period of at least 0.3 times the work time (at least a 0.3 recovery time to work time ratio [RT/WT]).

For example, a worker who continuously lifts for 2 hours would need at least a 36-minute recovery period 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.

Long duration. Long duration lifting tasks are those that have a duration of between 2-8 hours, with standard industrial rest allowances (morning, lunch, and afternoon rest breaks). Note: no weight limits are provided for more than 8 hours of work.

The difference in the required RT/WT ratio for the short (<1 hour) duration category, which is 1.2, and the moderate (1-2-hour) duration category, which is 0.3, is due to the difference in the magnitudes of the frequency multiplier values associated with each of the duration categories. Since the moderate category provides a larger reduction in the RWL than the short 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.

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. For work patterns such as this, F may be determined as follows, as long as the actual lifting frequency does not exceed 15 lifts per minute:

1. Compute the total number of lifts performed for the 15-minute period (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 13-5.

For example, if the work pattern for a job consists of a series of cyclical 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 $(10 \times 8)/15$, or 5.33

lifts per 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 per minute, followed by 2 minutes of recovery, the correct procedure would be to adjust the frequency according to the special procedure ($F = (10 \text{ lifts per minute} \times 5 \text{ minutes})/15 \text{ minutes} = 50/15 = 3.3 \text{ lifts per minute}$). The 2-minute recovery periods would not count toward the RT/WT ratio, however, and additional recovery periods would have to be provided as described above.

Frequency Restrictions

Lifting frequency (F) for repetitive lifting may range from 0.2 lifts per minute to a maximum frequency that is dependent on the vertical location of the object (V) and the duration of lifting (Table 13-5). Lifting above the maximum frequency results in a RWL of 0.0 (except for the special case of discontinuous lifting previously discussed, where the maximum frequency is 15 lifts per minute).

Frequency Multiplier

The FM value depends upon the average number of lifts per minute (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 0.2 lifts per minute, set the frequency equal to 0.2 lifts per minute. Otherwise, the FM is determined from Table 13-5.

COUPLING COMPONENT

Definition and 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 an 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 13-6. If there is any doubt about classifying a particular coupling design, the more stressful classification should be selected.

The decision tree shown in Figure 13-3 may be helpful in classifying the hand-to-object coupling.

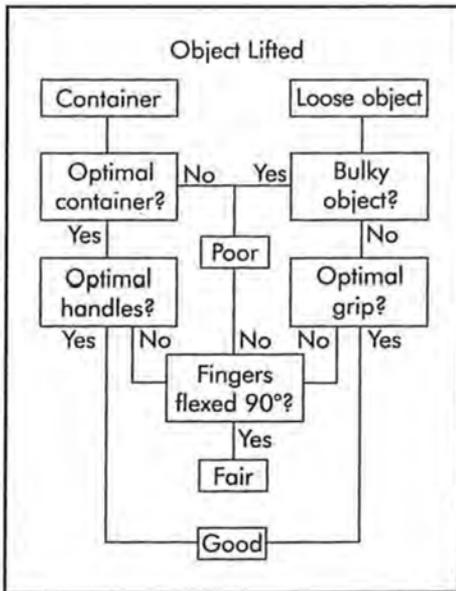


Figure 13-3 Decision tree for coupling quality.

Limitations

There are no limitations for classifying the coupling, but both hands must be observed when assessing the coupling. If one hand is predominately used to lift the load and the fingers are flexed at 90° under the load, then the coupling should be rated as fair, regardless of the position of the other hand.

Coupling Multiplier

Based on the coupling classification and vertical location of the lift, the coupling multiplier (CM) is determined from Table 13-7.

PROCEDURES

Prior to data collection, the analyst must decide if the job should be analyzed as a single-

or multi-task manual lifting job and if significant control is required at the lift's destination. This is necessary because the procedures differ according to the type of analysis required.

A manual lifting job may be analyzed as a single task if the task variables do not differ from task to task, or if only one task is of interest (single most stressful task). This may be the case if one of the tasks clearly has a dominant effect on strength demands, local-

ized muscle fatigue, or whole-body fatigue. On the other hand, if the task variables differ significantly between tasks, it may be more appropriate to analyze a job as a multi-task manual lifting job. A multi-task analysis is more difficult to perform than a single-task analysis because additional data and computations are required. The multi-task approach, however, will provide more detailed information about specific strength and physiological demands.

For many lifting jobs, it may be acceptable to use either the single- or multi-task approach. The single-task analysis should be used when possible, but when a job consists of more than one task and detailed information is needed to specify engineering modifications, then the multi-task approach is a reasonable method of assessing the overall physical demands. The multi-task procedure is more complicated than the single-task procedure, and requires a greater understanding of assessment terminology and mathematical concepts. Therefore, the decision to use the single- or multi-task approach should be based on: the need for detailed information about all facets of the multi-task lifting job; the need for accuracy and completeness of data in assessing the physiological demands of the task; and the analyst's level of understanding of the assessment procedures.

The decision about control at the destination is important because the physical demands on the worker may be greater at the destination of the lift than at the origin, especially when significant control is required. When significant control is required at the destination, for example, the physical stress is increased because the load will have to be accelerated upward to slow down its descent. This acceleration may be as great as the acceleration at the origin of the lift and may create high loads on the spine. Therefore, if significant control is required, then the *RWL* and *LI* should be determined at both locations, and the lower of the two values will specify the overall level of physical demand.

To perform a lifting analysis using the revised lifting equation, two steps are undertaken: data are collected at the worksite, and the recommended weight limit and lifting index values are computed using the single- or multi-task analysis procedure.

STEP 1: COLLECT DATA

The relevant task variables must be carefully measured and clearly recorded in a concise format. As mentioned previously, these variables include the horizontal location of the hands (*H*), vertical location of the hands (*V*), vertical displacement (*D*), asymmetric angle (*A*), lifting frequency (*F*), and coupling quality (*C*). Job anal-

ysis work sheets, as shown in Figure 13-4 for single-task jobs, or Figure 13-5 for multi-task jobs, provide a simple form for recording the task variables and the data needed to calculate the *RWL* and the *LI* values. A thorough job analysis is required to identify and catalog each independent lifting task in the worker's complete job. For multi-task jobs, data must be collected for each task.

STEP 2: SINGLE- AND MULTI-TASK PROCEDURES

Single-task Procedure

For a single-task analysis, step 2 consists of computing the *RWL* and the *LI*. This is accomplished as follows.

Calculate the *RWL* at the origin for each lift. For lifting tasks requiring significant control at the destination, calculate the *RWL* at both the origin and the destination of the lift. This procedure is required if the worker has to re-grasp the load near the destination of the lift, the worker has to momentarily hold the object at the destination, or the worker has to position or guide the load at the destination. The purpose of calculating the *RWL* at both the origin and destination of the lift is to identify the lift's most stressful location. Therefore, the lowest *RWL* value at the origin or destination should be used to compute the *LI* for the task, as this value would represent the limiting set of conditions.

The assessment is completed on the single-task work sheet by determining the *LI* for the task of interest. This is accomplished by comparing the actual weight of the load (*L*) lifted with the *RWL* value obtained from the lifting equation.

Multi-task Procedure

For a multi-task analysis, step two has three parts:

1. Compute the frequency-independent recommended weight limit (*FIRWL*) and single-task recommended weight limit (*STRWL*) for each task.
2. Compute the frequency-independent lifting index (*FILI*) and single-task lifting index (*STLI*) for each task.
3. Compute the composite lifting index (*CLI*) for the overall job.

Frequency-independent recommended weight limit (*FIRWL*). Compute the *FIRWL* value for each task by using the respective task variables and setting the frequency multiplier (*FM*) to a value of 1.0. The *FIRWL* for each task reflects the compressive force and muscle strength demands for a single repetition of that task. If significant control is required at the destination for any individual

Job Analysis Work Sheet												
Department _____						Job description _____						
Job title _____						_____						
Analyst's name _____						_____						
Date _____						_____						
Step 1. Measure and record task variables												
Object weight (lb)		Hand location (in.)				Vertical distance (in.)	Asymmetric angle (°)		Frequency rate	Duration	Object coupling	
		Origin		Destination			Origin	Destination				Lifts/min
L (avg)	L (max)	H	V	H	V	D	A	A	F		C	
Step 2. Determine the multipliers and compute the RWLs												
$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM$												
Origin	$RWL = 51 \times \square \times \square \times \square \times \square \times \square \times \square = \square \text{ lb}$											
Destination	$RWL = 51 \times \square \times \square \times \square \times \square \times \square \times \square = \square \text{ lb}$											
Step 3. Compute the lifting index												
Origin	Lifting index = $\frac{\text{Object weight (L)}}{RWL} = \frac{\quad}{\quad} = \square$											
Destination	Lifting index = $\frac{\text{Object weight (L)}}{RWL} = \frac{\quad}{\quad} = \square$											

Figure 13-4 Single-task job analysis work sheet.

Multi-task Job Analysis Work Sheet

Department _____
 Job title _____
 Analyst's name _____
 Date _____

Job description _____

Step 1. Measure and record task variables

Task no.	Object weight (lb)		Hand location (in.)				Vertical distance (in.)	Asymmetric angle (°)		Frequency rate	Duration (hr)	Coupling
			Origin		Destination			Origin	Destination			
	L (avg)	L (max)	H	V	H	V	D	A	A	F		C

Step 2. Compute multipliers and FIRWL, STRWL, FILI, and STLI for each task

Task no.	LC	HM	VM	DM	AM	CM	FIRWL × FM	STRWL	FILI = L/FIRWL	STLI = L/STRWL	New task number	F
	51											
	51											
	51											
	51											
	51											

Step 3. Compute the composite lifting index for the job (after renumbering tasks)

$CLI = STLI_1 + \Delta FILI_2 + \Delta FILI_3 + \Delta FILI_4 + \Delta FILI_5$	$FILI_2 (1/FM_{1,2} - 1/FM_1)$	$FILI_3 (1/FM_{1,2,3} - 1/FM_{1,2})$	$FILI_4 (1/FM_{1,2,3,4} - 1/FM_{1,2,3})$	$FILI_5 (1/FM_{1,2,3,4,5} - 1/FM_{1,2,3,4})$
CLI =				

Figure 13-5 Multi-task job analysis work sheet.

task, the *FIRWL* must be computed at both the origin and the destination of the lift, as previously described for single-task analysis.

Single-task recommended weight limit (*STRWL*). Compute the *STRWL* for each task by multiplying its *FIRWL* by its appropriate *FM* value. The *STRWL* for a task reflects the overall demands of that task, assuming it was the only task being performed. Note: this value does not reflect the overall demands of the task when the other tasks are considered. Nevertheless, it is helpful in determining the extent of excessive physical stress for an individual task.

Frequency-independent lifting index (*FILI*). The *FILI* is computed for each task by dividing the maximum load weight (*L*) for that task by its respective *FIRWL*. The maximum weight is used to compute the *FILI* because the maximum weight determines the maximum biomechanical loads to which the body will be exposed, regardless of the frequency of occurrence. Thus, the *FILI* can identify individual tasks with potential strength problems for infrequent lifts. If any of the *FILI* values exceed a value of 1.0, then job design changes may be needed to decrease the strength demands.

Single-task lifting index (*STLI*). The *STLI* is computed for each task by dividing the average load weight (*L*) for that task by the respective *STRWL*. The average weight is used to compute the *STLI* because it provides a better representation of the metabolic demands, which are distributed across the tasks, rather than dependent on individual tasks. The *STLI* can be used to identify individual tasks with excessive physical demands (tasks that would result in fatigue). The *STLI* values do not indicate the relative stress of the individual tasks in the context of the whole job, but they can be used to prioritize the individual tasks according to the magnitude of their physical stress. Thus, if any of the *STLI* values exceed a value of 1.0, then ergonomic changes may be needed to decrease the overall physical demands of the task. Note: it may be possible to have a job in which all individual tasks have a *STLI* less than 1.0 and yet is physically demanding due to the combined demands of the tasks. In cases where the *FILI* exceeds the *STLI* for any task, the maximum weights may represent a significant problem, making careful evaluation necessary.

Composite lifting index (*CLI*). The assessment is completed on the multi-task work sheet by determining the composite lifting index (*CLI*) for the overall job. The *CLI* is computed as follows:

1. The tasks are renumbered in order of decreasing physical stress, from the task with the greatest *STLI* down to the task

with the smallest *STLI*. The tasks are renumbered in this way so that the more difficult tasks are considered first.

2. The *CLI* for the job is then computed according to the following formula:

$$CLI = STLI_1 + \Sigma \Delta LI$$

where:

$$(\Sigma \Delta LI = FILI_2 \times ((1 \div FM_{1,2}) - (1 \div FM_1))) + FILI_3 \times ((1 \div FM_{1,2,3}) - (1 \div FM_{1,2})) + FILI_4 \times ((1 \div FM_{1,2,3,4}) - (1 \div FM_{1,2,3})) + FILI_n \times ((1 \div FM_{1,2,3,4,\dots,n}) - (1 \div FM_{1,2,3,\dots,(n-1)}))$$

Note: the numbers in the subscripts refer to the new task numbers; and the *FM* values are determined from Table 13-5, based on the sum of the frequencies for the tasks listed in the subscripts.

An Example

The following example is provided to demonstrate this step of the multi-task procedure. Assume that an analysis of a typical three-task job provided the results shown in Table 13-8.

Table 13-8. Computations from multi-task example

Task #	Load (L) weight lb (kg)	Task frequency (F)	FIRWL	FM	STRWL	FILI	STLI	New task #
1	66.1 (30)	1	20	0.94	18.8	1.50	1.6	1
2	44.1 (20)	2	20	0.91	18.2	1.00	1.1	2
3	22.0 (10)	4	15	0.84	12.6	0.67	0.8	3

To compute the composite lifting index (*CLI*) for this job, the tasks are renumbered in order of decreasing physical stress, beginning with the task with the greatest *STLI*. In this case, as shown in Table 13-8, the task numbers do not change. Next, the *CLI* is computed according to the formula previously shown. The task with the greatest *CLI* is Task 1 (*STLI* = 1.6). The sum of the frequencies for Tasks 1 and 2 is 1 + 2 or 3, and the sum of the frequencies for Tasks 1, 2, and 3 is 1 + 2 + 4, or 7. Then, from Table 13-5, *FM*₁ is 0.94, *FM*_{1,2} is 0.88, and *FM*_{1,2,3} is 0.70. Finally, the *CLI* = 1.6 +

$1.0 (1/0.88 - 1/0.94) + 0.67(1/0.70 - 1/0.88) = 1.6 + .07 + .20 = 1.9$.
 Note: the *FM* values were based on the sum of the frequencies for the subscripts, the vertical height, and the duration of lifting.

APPLYING THE EQUATIONS

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 (horizontal, vertical, frequency).
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 the *RWL* is not exceeded; if the weight is fixed, then the task variables could be optimized so that the weight is not exceeded by 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 ranked according to the *LI*, and a control strategy could be developed (jobs with lifting indices above 1.0 or higher would benefit the most from redesign).

RATIONALE AND LIMITATIONS FOR LI

The NIOSH *RWL* and *LI* equations 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, the level of risk for a given worker increases, and a greater percentage of the work force 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 an 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 Waters et al. (1993), which provides a discussion of the criteria underlying the lifting equation and of the individual multipliers, and identifies both the assumptions and uncertainties in the scientific studies that associate manual lifting and low-back injuries.

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 work force (Waters et al. 1993). Hence, lifting jobs should be designed 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 (lifting tasks that would exceed a *LI* of 1.0) without significantly increasing their risk of work-related injury above the baseline level (Chaffin and Andersson 1984). Those who endorse the use of selection criteria believe that the criteria must be based on research studies, empirical observations, or theoretical considerations that include job-related strength testing and/or aerobic capacity testing. Even these experts agree, however, that many workers will be at a significant risk of a work-related injury when performing highly stressful lifting tasks (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 work force 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.

EXAMPLE PROBLEMS

Two sample problems are provided to demonstrate the proper application of the lifting equation and procedures. The procedures offer a method for determining the level of physical stress associated with a specific set of lifting conditions and assist in identifying the contribution of each job-related factor. The examples can help guide the development of an ergonomic redesign strategy. Specifically, for each example, a job description, job analysis, haz-

ard assessment, redesign suggestion, illustration, and completed work sheet are provided.

A series of general design/redesign suggestions for each job-related risk factor are provided in Table 13-9. These suggestions can be used to develop a practical ergonomic design/redesign strategy.

Table 13-9. General design/redesign suggestions

If $HM < 1.0$	Bring the load closer to the worker by removing any horizontal barriers or reducing the size of the object. Lifts near the floor should be avoided; if unavoidable, the object should fit easily between the legs.
If $VM < 1.0$	Raise/lower the origin/destination of the lift. Avoid lifting near the floor or above the shoulders.
If $DM < 1.0$	Reduce the vertical distance between the origin and the destination of the lift.
If $AM < 1.0$	Move the origin and destination of the lift closer together to reduce the angle of twist, or move the origin and destination further apart to force the worker to turn the feet and step, rather than twist the body.
If $FM < 1.0$	Reduce the lifting frequency rate, reduce the lifting duration, or provide longer recovery periods (i.e., light work period).
If $CM < 1.0$	Improve the hand-to-object coupling by providing optimal containers with handles or handhold cutouts, or improve the handholds for irregular objects.
If the RWL at the destination < at the origin	Eliminate the need for significant control of the object at the destination by redesigning the job or modifying the container/object characteristics. (See requirements for significant control in text.)

Loading Supply Rolls, Example 1

Job description. With both hands directly in front of the body, a worker lifts the core of a 35-lb (16-kg) roll of paper from a cart, then shifts the roll in the hands and holds it by the sides to position it on a machine, as shown in Figure 13-6. Significant control of the roll is required at the destination of the lift. Also, the worker must crouch at the destination of the lift to support the roll in front of the body, but does not have to twist.

Job analysis. The task variable data are measured and recorded on the job analysis work sheet (Figure 13-7). The vertical location of the hands is 27 in. (69 cm) at the origin, and 10 in. (25 cm) at the

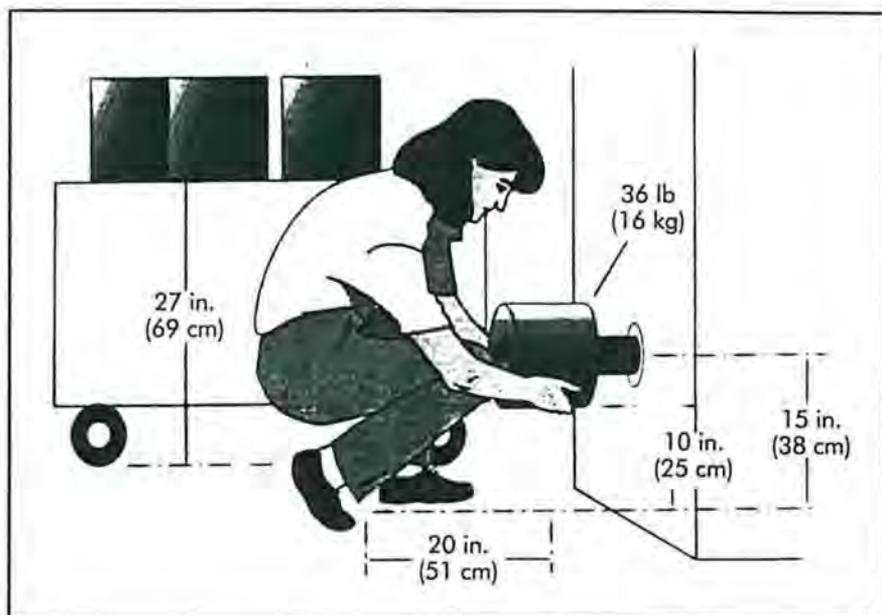


Figure 13-6 Loading supply rolls.

destination. The horizontal location of the hands is 15 in. (38 cm) at the origin and 20 in. (51 cm) at the destination. The asymmetric angle is 0° at both the origin and the destination, and the frequency is four lifts per shift (less than 0.2 lifts per minute for less than 1 hour—(see Table 13-5).

Using Table 13-6, the coupling is classified as poor because the worker must reposition the hands at the destination of the lift and he or she cannot flex the fingers to the desired 90° angle (hook grip). No asymmetric lifting is involved ($A = 0$), and significant control of the object is required at the destination of the lift. Thus, the *RWL* should be computed at both the origin and the destination of the lift. The multipliers are computed from the lifting equation or determined from the multiplier tables (Tables 13-1 to 13-5, and Table 13-7). As shown in Figure 13-7, $RWL = 28.0$ lb (13 kg) at the origin and $RWL = 18.1$ lb (8 kg) at the destination for this activity.

Hazard assessment. The weight to be lifted (35 lb [16 kg]) is greater than the *RWL* at both the origin and destination of the lift (28.0 lb [13 kg] and 18.1 lb [8 kg], respectively). At the origin, $LI = 35$ lb [16 kg]/28.0 lb [13 kg] = 1.3; at the destination, $LI = 35$ lb [16 kg]/18.1 lb [8 kg] = 1.9. These values indicate that this job

Job Analysis Work Sheet											
Department		Shipping						Job description			
Job title		Packager						Loading paper supply rolls			
Analyst's name		_____						_____			
Date		_____						Example 1			
Step 1. Measure and record task variables											
Object weight (lb)		Hand location (in.)				Vertical distance (in.)	Asymmetric angle (°)		Frequency rate	Duration	Object coupling
		Origin		Destination			Origin	Destination			
L (avg)	L (max)	H	V	H	V	D	A	A	F	hr	C
35	35	15	27	20	10	17	0	0	<.2	<1	Poor
Step 2. Determine the multipliers and compute the RWLs											
$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM$											
Origin		$RWL = 51 \times .67 \times .98 \times .93 \times 1.0 \times 1.0 \times .90 = 28.0 \text{ lb}$									
Destination		$RWL = 51 \times .50 \times .85 \times .93 \times 1.0 \times 1.0 \times .90 = 18.1 \text{ lb}$									
Step 3. Compute the lifting index											
Origin		Lifting index = $\frac{\text{Object weight (L)}}{RWL} = \frac{35}{28.0} = 1.3$									
Destination		Lifting index = $\frac{\text{Object weight (L)}}{RWL} = \frac{35}{18.1} = 1.9$									

Figure 13-7 Job analysis work sheet on which task variable data is measured and recorded.

is somewhat stressful at the origin, but more stressful at the destination of the lift.

Redesign suggestions. The first choice for reducing the risk of injury for workers performing this task would be to adapt the cart so that the paper rolls could be easily pushed into position on the machine, without manually lifting them.

If the cart cannot be modified, then the results of the equation may be used to suggest task modifications. The work sheet displayed in Figure 13-7 indicates that the multipliers with the smallest magnitude (those providing the greatest penalties) are 0.50 for the *HM* at the destination, 0.67 for the *HM* at the origin, 0.85 for the *VM* at the destination, and 0.90 for the *CM* value. Using Table 13-9, the following job modifications are suggested:

1. Bring the load closer to the worker by making the roll smaller so that it can be lifted from between the worker's legs. This will decrease the *H* value, which in turn will increase the *HM* value.
2. Raise the height of the destination to increase the *VM*.
3. Improve the coupling to increase the *CM*.

If the size of the roll cannot be reduced, then the vertical height (*V*) at the destination should be increased. Figure 13-8 shows that if *V* were increased to about 30 in. (76 cm), then *VM* would be increased from 0.85 to 1.0; the *H* value would be decreased from 20 in. to 15 in. (51 cm to 38 cm), which would increase *HM* from 0.50 to 0.67; and *DM* would be increased from 0.93 to 1.0. As shown in Figure 13-8, the final *RWL* would be increased from 18.1 lb to 30.8 lb (8 kg to 14 kg), and the *LI* at the destination would decrease from 1.9 to 1.1.

In some cases, redesign may not be feasible. In these cases, the use of a mechanical lift may be more suitable. As an interim control strategy, two or more workers may be assigned to lift the supply roll.

Comments. The horizontal distance (*H*) is a significant factor that may be difficult to reduce, because the size of the paper rolls may be fixed. Moreover, redesign of the machine may not be practical. Therefore, elimination of the manual lifting component of the job may be more appropriate than job redesign.

Dish-washing Machine Unloading, Example 2

Job description. A worker manually lifts trays of clean dishes from a conveyor at the end of a dish-washing machine and loads them on a cart as shown in Figure 13-9. The trays are filled with assorted dishes (glasses, plates, bowls) and silverware. The job takes

Job Analysis Work Sheet											
Department		Shipping						Job description			
Job title		Packager						Loading paper supply rolls			
Analyst's name											
Date								Modified example 1			
Step 1. Measure and record task variables											
Object weight (lb)		Hand location (in.)				Vertical distance (in.)	Asymmetric angle (°)		Frequency rate	Duration	Object coupling
		Origin		Destination			Origin	Destination			
L (avg)	L (max)	H	V	H	V	D	A	A	F	(hr)	C
35	35	15	27	15	30	3	0	0	<.2	<1	Poor
Step 2. Determine the multipliers and compute the RWLs											
$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM$											
Origin		$RWL = 51 \times .67 \times .98 \times 1.0 \times 1.0 \times 1.0 \times .90 = 30.1 \text{ lb}$									
Destination		$RWL = 51 \times .67 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times .90 = 30.8 \text{ lb}$									
Step 3. Compute the lifting index											
Origin		Lifting index = $\frac{\text{Object weight (L)}}{RWL} = \frac{35}{30.1} = 1.2$									
Destination		Lifting index = $\frac{\text{Object weight (L)}}{RWL} = \frac{35}{30.8} = 1.1$									

Figure 13-8 Modified job analysis work sheet.

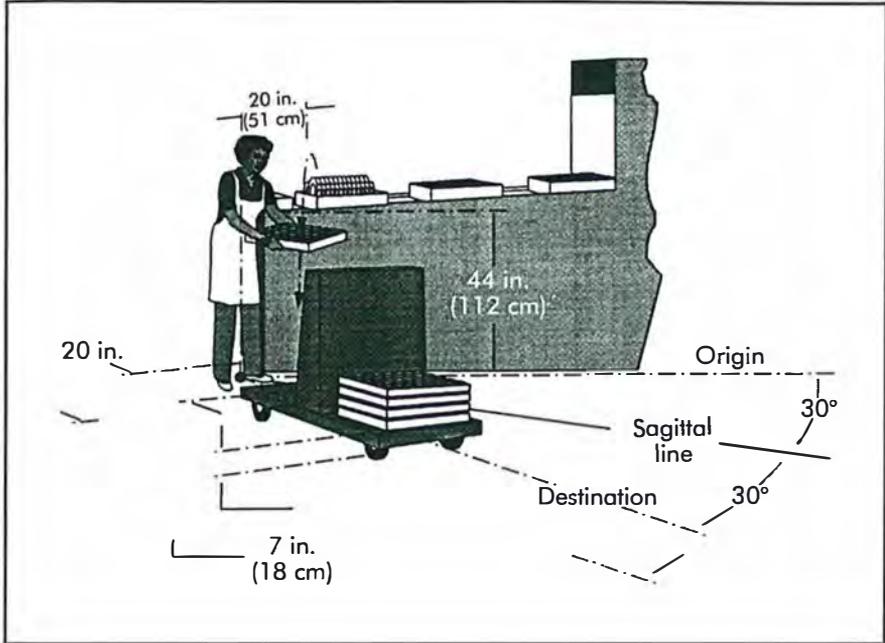


Figure 13-9 Dishwashing machine unloading.

between 45 minutes and 1 hour to complete, and the lifting frequency rate averages five lifts per minute. Workers usually twist their body to one side to lift the trays (asymmetric lift) and then rotate their body to the other side to lower the trays to the cart in one smooth continuous motion. The asymmetric angle (A) varies between workers and within workers, but there is usually equal asymmetry to either side. During the lift, the worker may take a step toward the cart. The trays have well-designed handhold cut-outs and are made of lightweight materials.

Job analysis. The task variable data are measured and recorded on the job analysis work sheet (Figure 13-10). At the origin of the lift, the horizontal distance (H) is 20 in. (51 cm), the vertical distance (V) is 44 in. (112 cm), and the angle of asymmetry (A) is 30° . At the destination of the lift, H is 20 in. (51 cm), V is 7 in. (18 cm), and A is 30° . The trays normally weigh between 5 lb (2.3 kg) and 20 lb (9.1 kg), but for this example, assume that all of the trays weigh 20 lb (9.1 kg).

Using Table 13-6, the coupling is classified as “good.” Significant control is required at the destination of the lift. Using Table 13-5, the

FM is determined to be 0.80. As shown in Figure 13-10, the *RWL* is 14.4 lb (6.5 kg) at the origin and 13.3 lb (6 kg) at the destination.

Hazard assessment. The weight to be lifted (20 lb [9.1 kg]) is greater than the *RWL* at either the origin or destination of the lift (14.4 lb [6.5 kg] and 13.3 lb [6 kg], respectively). The *LI* at the origin is $20/14.4 = 1.4$ and the *LI* at the destination is 1.5. These results indicate that this lifting task would be stressful for some workers.

Redesign suggestions. The work sheet shows that the smallest multipliers (the greatest penalties) are 0.50 for the *HM*, 0.80 for the *FM*, 0.83 for the *VM*, and 0.90 for the *AM*. Using Table 13-9, the following job modifications are suggested:

- Bring the load closer to the worker to increase *HM*;
- Reduce the lifting frequency rate to increase *FM*;
- Raise the destination of the lift to increase *VM*; and
- Reduce the angle of twist to increase *AM* by either moving the origin and destination closer together or moving them further apart.

Since the horizontal distance (*H*) is dependent on the width of the tray in the sagittal plane, this variable can only be reduced by using smaller trays. Both the *DM* and *VM*, however, can be increased by lowering the height of the origin and increasing the height of the destination. For example, if the height at both the origin and destination is 30 in. (76 cm), then *VM* and *DM* are 1.0, as shown in the modified work sheet (Figure 13-11). Moreover, if the cart is moved so that reaching to the side is eliminated, the *AM* can be increased from 0.90 to 1.00. As shown in Figure 13-11, with these redesign suggestions, the *RWL* can be increased from 13.3-20.4 lb (6-9.3 kg), and the *LI* values are reduced to 1.0.

Comments. This analysis was based on a 1-hour work session. If a subsequent work session begins before the appropriate recovery period has elapsed (1.2 hours), then the 1-2-hour or 2-8-hour category would be used to compute the *FM* value.

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Job Analysis Work Sheet											
Department		Food service						Job description			
Job title		Cafeteria worker						Unloading a dish-washing machine			
Analyst's name											
Date								Modified example 2			
Step 1. Measure and record task variables											
Object weight (lb)		Hand location (in.)				Vertical distance (in.)	Asymmetric angle (°)		Frequency rate	Duration	Object coupling
		Origin		Destination			Origin	Destination			
L (avg)	L (max)	H	V	H	V	D	A	A	F		C
20	20	20	30	20	30	0	0	0	5	<1	Good
Step 2. Determine the multipliers and compute the RWLs											
$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM$											
Origin		$RWL = 51 \times .50 \times 1.0 \times 1.0 \times 1.0 \times .80 \times 1.0 = 20.4 \text{ lb}$									
Destination		$RWL = 51 \times .50 \times 1.0 \times 1.0 \times 1.0 \times .80 \times 1.0 = 20.4 \text{ lb}$									
Step 3. Compute the lifting index											
Origin		Lifting index = $\frac{\text{Object weight (L)}}{RWL} = \frac{20}{20.4} = 1.0$									
Destination		Lifting index = $\frac{\text{Object weight (L)}}{RWL} = \frac{20}{20.4} = 1.0$									

Figure 13-11 Modified job analysis work sheet showing the decreased LI values.

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Library of Congress Catalog Card Number: 98-060113
ISBN: 0-87263-485-X

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Printed in the United States of America