chapter twenty

Revised NIOSH lifting equation

Thomas R. Waters

Contents

20.1 Introduction

This chapter provides information about a revised equation developed by the National Institute for Occupational Safety and Health (NIOSH) for assessing the physical demands of certain two-handed manual lifting tasks, which was described in an article by Waters et al. (1993). The chapter contains sections describing what factors need to be measured, how they should be measured, what procedures should be used, and how the results can be used to ergonomically design new jobs or make decisions about redesigning existing jobs that may be hazardous. The chapter defines all pertinent terms and presents the mathematical formulas and procedures needed to properly apply the NIOSH lifting equation (NLE). Several example problems are also provided to demonstrate how the equations should be used. An expanded, more detailed version of this chapter is contained in a NIOSH report entitled "Applications Manual for the Revised NIOSH Lifting Equation" (Waters et al., 1994).

Historically, NIOSH has recognized the problem of work-related back injuries, and published the *Work Practices Guide for Manual Lifting* (WPG) in 1981 (NIOSH, 1981). The NIOSH WPG 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, 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.† 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 rationale and criterion for the development of the revised NLE are provided in a journal article entitled "Revised NIOSH Equation for the Design and Evaluation of Manual Lifting Tasks," (Waters et al., 1993). We suggest that those users 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. The 1991 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, this chapter provides a more complete description of the method and limitations for using the revised equation than does the article by Waters et al. (1993).

Although there is limited data examining the validity or effectiveness of the revised lifting equation to identify lifting jobs with increased risk of low back disorders, the recommended weight limits derived from the revised equation are consistent with, or lower than, those generally reported in the literature as being safe for workers (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. A later section of this chapter provides a summary of studies examining the effectiveness of the NIOSH equation to identify manual lifting jobs with increased risk of lifting-related low back pain (LBP).

Finally, it should be stressed that the NLE is only one tool in a comprehensive effort to prevent work-related low back pain and disability. Some examples of other approaches are described elsewhere (ASPH/NIOSH, 1986). Moreover, lifting is only one of the causes 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 19).

20.2 *Definition of terms*

This section provides the basic technical information needed to properly use the revised lifting equation to evaluate a variety of two-handed manual lifting tasks. Definitions and data requirements for the revised lifting equation are also provided.

* 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.

† For this document, the revised 1991 NIOSH lifting equation will be identified simply as "the revised lifting equation." The abbreviation WPG 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* (NIOSH, 1981).

20.2.1 Recommended weight limit

The recommended weight limit (RWL) is the principal product of the revised NLE. 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 h) 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 concept behind the revised NLE is to start with a recommended weight that is considered safe for an "ideal" lift (i.e., load constant equal to 51 lbs) and then reduce the weight as the task becomes more stressful (i.e., as 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, which include the (1) horizontal distance of the load from the worker (*H*), (2) vertical height of the lift (*V*), (3) vertical displacement during the lift (*D*), (4) angle of asymmetry (*A*), (5) frequency (*F*) and duration of lifting, and (6) quality of the hand-to-object coupling (C). 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., the recommended weight limit for that task would be reduced from the ideal starting weight.

The RWL is defined as follows:

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

where

		Metric	U.S. Customary
LC	Load constant	23 kg	51 lbs
HM	Horizontal multiplier	$(25/H)$	$(10/H)$
VM	Vertical multiplier	$1 - (0.003 \times \|V - 75\|)$	$1 - (0.0075 \times \|V - 30\|)$
DM	Distance multiplier	$0.82 + (4.5/D)$	$0.82 + (1.8/D)$
AM	Asymmetric multiplier	$1 - (0.0032A)$	$1 - (0.0032A)$
FM	Frequency multiplier	From Table 20.5	From Table 20.5
CM	Coupling multiplier	From Table 20.7	From Table 20.7

The term "task variables" refers to the measurable task-related measurements that are used as input data for the formula (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).

20.2.2 Measurement requirements

The following list briefly describes the measurements required to use the revised NLE. Details for each of the variables is presented later in this chapter (see Section 20.4).

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

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

D = Vertical travel distance between the origin and the destination of the lift (cm or in.).
A = Angle of asymmetry—angular displacement of the load from the worker's sagittal plane. Measure at the origin and destination of the lift (degrees).
F = Average frequency rate of lifting measured in lifts/min.
Duration is defined to be 1, 2, or 8 h assuming appropriate recovery allowances (See Table 20.5).
C = Quality of hand-to-object coupling (quality of interface between the worker and the load being lifted). The quality of the coupling is categorized as good, fair, or poor, depending upon the type and location of the coupling, the physical characteristics of load, and the vertical height of the lift.

20.2.3 *Lifting index*

The lifting index (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:

$$\text{LI} = \frac{\text{load weight}}{\text{recommended weight limit}} = \frac{L}{\text{RWL}}$$

where load weight (L) = weight of the object lifted (lbs or kg).

20.2.4 *Miscellaneous terms*

Lifting task: Lifting task is 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 midpoint between the ankles, in inches or centimeters (measure at the origin and destination of lift). See Figure 20.1.

Vertical location (V): Distance of the hands above the floor, in inches or centimeters (measure at the origin and destination of lift). See Figure 20.1.

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): The angular measure of how far the object is displaced from the front (midsagittal 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 20.2. 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 the extent of body twist.

Neutral body position: It 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.

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

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 h), moderate (1–2 h), or long (2–8 h), 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.

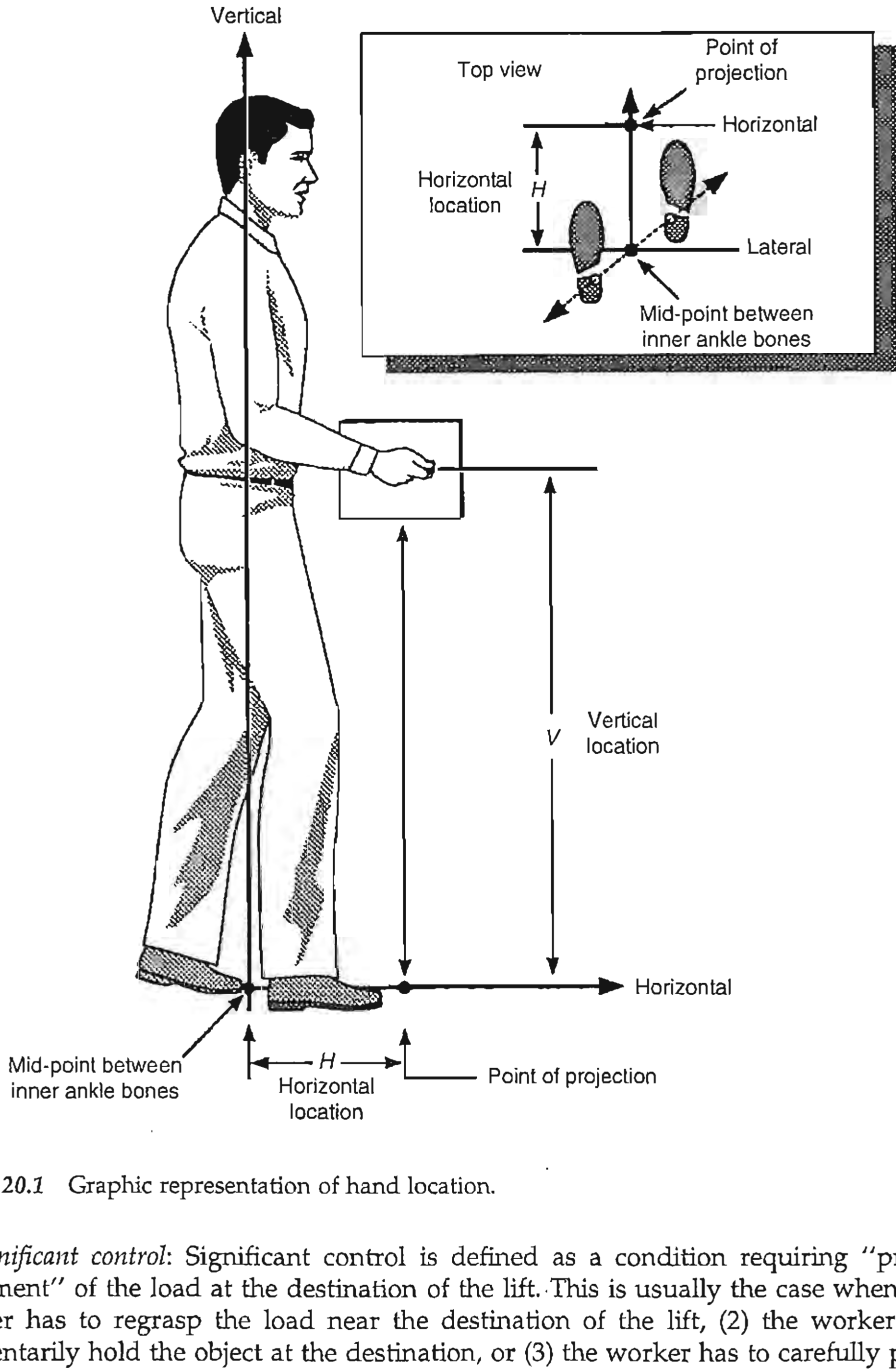

Figure 20.1 Graphic representation of hand location.

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 regrasp the load near the destination of the lift, (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.

20.3 Limitations of equation

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, physiological, and psychophysical assumptions

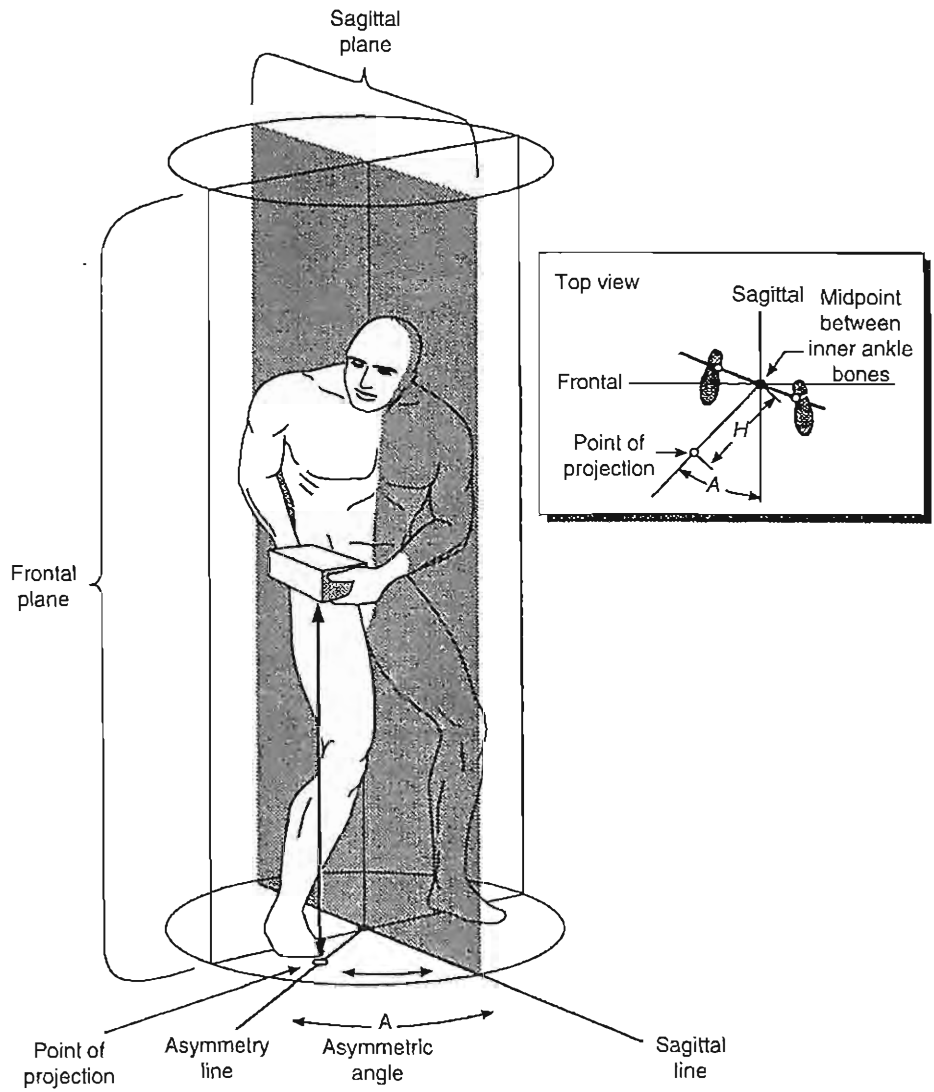

Figure 20.2 Graphic representation of angle of asymmetry (A).

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 in which the application of the lifting equation could either under- or overestimate 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.

The revised NIOSH lifting equation does not apply if any of the following occur:

Lifting or lowering with one hand
Lifting or lowering for over 8 h
Lifting or lowering while seated or kneeling

Lifting or lowering in a restricted work space
Lifting or lowering unstable objects
Lifting or lowering while carrying, pushing, or pulling
Lifting or lowering with wheelbarrows or shovels
Lifting or lowering with high-speed motion (faster than about 30 in./s)
Lifting or lowering with unreasonable foot–floor coupling (<0.4 coefficient of friction between the sole and the floor)
Lifting or lowering in an unfavorable environment (temperature significantly outside 66°F–79°F [19°C–26°C] range; relative humidity outside 35%–50% range)

20.4 Obtaining and using the data

20.4.1 Horizontal component

20.4.1.1 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 (i.e., load center), as defined by the large middle knuckle of the hand (Figure 20.1). Typically, the worker's feet are not aligned with the midsagittal plane, as shown in Figure 20.1, 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, such as when a precision placement is needed, then *H* should be measured at both the origin and destination of the lift. Also, if the worker leans over on one foot during lifting, concentrating nearly all of their support on one foot while using the other leg and foot as a counterbalance so that they can reach out further to pick up the load, the *H* variable is measured from a point directly below the weight-bearing foot, rather than the midpoint between the ankles. In cases where it is not clear that the weight is concentrated primarily on one foot, the point between the ankles should still be used as the reference point for measurement of the horizontal location (*H*). It also important to note that it has also come to our attention that users sometimes overestimate the magnitude of the horizontal location (*H*) and the asymmetric angle (*A*) for some types of lifts because they mistakenly measure the task variables at the incorrect location for the origin of the lift. This may occur when the lifter stands with the side of their body next to a table or shelf and reaches over to slide the object horizontally toward the front of the body as they begin the lift. When the lift is performed this way, the load actually moves horizontally toward the front of the body before it actually begins to move vertically. When this type of lift is analyzed, the task variables should be measured at the actual location where the object first begins to move upward (liftoff point), rather than at the point where the object first begins to move horizontally. This change will generally result in smaller *H* values than would have been determined if the measurements had been taken at the point where the object first began to move horizontally rather than vertically.

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:

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

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

20.4.1.2 *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. from the ankles, most objects that are closer than this cannot be lifted without encountering interference from the abdomen. Although 25 in. (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 in. from the ankles normally cannot be lifted vertically without some loss of balance.

20.4.1.3 *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 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. (63 cm). If H is greater than 25 in., then HM = 0. The HM value can be computed directly or determined from Table 20.1.

20.4.2 *Vertical component vertical*

20.4.2.1 *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 midpoint between the hand grasps, as defined by the large middle knuckle. The coordinate system is illustrated in Figure 20.1.

Table 20.1 Horizontal Multiplier

H in.	HM	*H* cm	HM
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

20.4.2.2 Vertical restrictions

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

20.4.2.3 Vertical multiplier

To determine the vertical multiplier (VM), the absolute value or deviation of V from an optimum height of 30 in. (75 cm) is calculated. A height of 30 in. above floor level is considered "knuckle height" for a worker of average height (66 in. or 165 cm). The VM is $(1-(0.0075 \times |V - 30|))$ for V measured in inches, and VM is $(1-(0.003 \times |V - 75|))$, for V measured in centimeters.

When V is at 30 in. (75 cm), the 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 in. (175 cm) height VM is 0.7. If V is greater than 70 in., then VM = 0. The VM value can be computed directly or determined from Table 20.2.

20.4.3 Distance component

20.4.3.1 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

Table 20.2 Vertical Multiplier

V in.	VM	V cm	VM
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 20.3 Distance Multiplier

D in.	DM	D cm	DM
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	—	—

(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.

20.4.3.2 *Distance restrictions*

The distance variable (*D*) is assumed to be at least 10 in. (25 cm), and no greater than 70 in. (175 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).

20.4.3.3 *Distance multiplier*

The distance multiplier (DM) is $(0.82 + (1.8/D))$ for *D* measured in inches, and DM is $(0.82 + (4.5/D))$ 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 is 1.0 when *D* is set at 10 in. (25 cm); DM is 0.85 when $D=70$ in. (175 cm). Thus, DM ranges from 1.0 to 0.85 as the *D* varies from 0 to 70 in. (0–175 cm). The DM value can be computed directly or determined from Table 20.3.

20.4.4 *Asymmetry component*

20.4.4.1 *Definition and measurement*

Asymmetry refers to a lift that begins or ends outside the midsagittal plane (see Figure 20.2). 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.*

* 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.

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

1. Origin and destination of the lift are oriented at an angle to each another.
2. Lifting motion is across the body, such as occurs in swinging bags or boxes from one location to another.
3. 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 20.2, is operationally defined as the angle between the asymmetry line and the midsagittal 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 (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 midsagittal 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. Remember, that A should be measured at the liftoff point, when the load actually begins to move upward, rather than at the point when the object begins to move horizontally. This is often easiest to see when the job is videotaped and the videotape is played back at a slow speed or frame by frame.

20.4.4.2 Asymmetry restrictions

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

20.4.4.3 Asymmetric multiplier

The asymmetric multiplier (AM) is $1 - (0.0032A)$. 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 0. The AM value can be computed directly or determined from Table 20.4.

20.4.5 Frequency component

20.4.5.1 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 min period. Because of the potential variation in work patterns, analysts may have difficulty obtaining an accurate or representative 15 min work sample for com-

Table 20.4 Asymmetric Multiplier

A (deg)	AM
0	1.00
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

puting 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).

20.4.5.2 Lifting duration

Lifting duration is classified into three categories based on the pattern of continuous work-time and recovery-time (i.e., 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, light assembly work, etc. The three categories are short-duration, moderate-duration, and long-duration.

1. Short-duration defines lifting tasks that have a work duration of 1 h or less, followed by a recovery time equal to 1.0 times the work time (i.e., at least a 1.0 recovery-time to work-time ratio (RT/WT)). (Note: the RT/WT ratio has been changed from 1.2 to 1.0 since the equation was originally published.)

For example, to be classified as short-duration, a 45 min lifting job must be followed by at least a 45 min recovery period prior to initiating a subsequent lifting session. If the required recovery time is not met for a job of 1 h 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 min, then performs a light work task for 10 min, and then lifts for an additional 45 min period. In this case, the recovery time between lifting sessions (10 min) is less than 1.0 times the initial 30 min work time (36 min). Thus, the two work times (30 and 45 min) must be added together to determine the duration. Since the total work time (75 min) exceeds 1 h, the job is classified as moderate-duration. On the other hand, if the recovery period between lifting sessions was increased to 30 min, then the short-duration category would apply, which would result in a larger frequency multiplier (FM) value.

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 min 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, the lifting frequency (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 min 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 FM from Table 20.5.

For example, if the work pattern for a job consists of a series of cyclic sessions requiring 8 min of lifting followed by 7 min 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/min. If the worker lifted continuously for more than 15 min, however, then the actual lifting frequency (10 lifts per min) 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 min sampling period are not considered

Table 20.5 Frequency Multiplier Table

Frequency[a] (F) (Lifts/min)	Work Duration: 1 h, $V < 30$[b]	1 h, $V \geq 30$	>1 but 2 h, $V < 30$	>1 but 2 h, $V \geq 30$	>2 but 8 h, $V < 30$	>2 but 8 h, $V \geq 30$
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	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.72	0.45	0.45
5	0.80	0.80	0.60	0.60	0.35	0.35
6	0.75	0.75	0.50	0.50	0.27	0.27
7	0.70	0.70	0.42	0.42	0.22	0.22
8	0.60	0.60	0.35	0.35	0.18	0.18
9	0.52	0.52	0.30	0.30	0.00	0.15
10	0.45	0.45	0.26	0.26	0.00	0.13
11	0.41	0.41	0.00	0.23	0.00	0.00
12	0.37	0.37	0.00	0.21	0.00	0.00
13	0.00	0.34	0.00	0.00	0.00	0.00
14	0.00	0.31	0.00	0.00	0.00	0.00
15	0.00	0.28	0.00	0.00	0.00	0.00
>15	0.00	0.00	0.00	0.00	0.00	0.00

[a] For lifting less frequently than once per 5 min, set $F = 0.2$ lifts/min.
[b] Values of V are in inches.

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 min of continuous lifting at a rate of 10 lifts/min, followed by 2 min of recovery, the correct procedure would be to adjust the frequency according to the special procedure (i.e., $F=$ (10 lifts/min $\times$ 5 min)/15 min $=50/15=3.4$ lifts/min). The 2 min recovery periods would not count toward the RT/WT ratio, however, and additional recovery periods would have to be provided as described above.

2. Moderate-duration defines lifting tasks that have a duration of more than 1 h, but not more than 2 h, 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 h, then a recovery period of at least 36 min 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 h, then the job must be classified as a long-duration lifting task.

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

The difference in the required RT/WT ratio for the short (less than 1 h) duration category, which is 1.0, and the moderate (1–2 h) 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 results in larger reductions 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.

20.4.5.3 *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 20.5). 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/min).

20.4.5.4 *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 0.2 lifts per min, set the frequency equal to 0.2 lifts/min. Otherwise, the FM is determined from Table 20.5.

20.4.6 *Coupling component*

20.4.6.1 *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 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, whereas 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 20.6. If there is any doubt about classifying a particular coupling design, the more stressful classification should be selected.

The decision tree shown in Figure 20.3 may be helpful in classifying the hand-to-object coupling.

20.4.6.2 *Coupling multiplier*

Based on the coupling classification and vertical location of the lift, the coupling multiplier (CM) is determined from Table 20.7.

Table 20.6 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° (see note 4 below).	2. Lifting nonrigid bags (i.e., bags that sag in the middle).

1. An optimal handle design has 0.75–1.5 in. (1.9–3.8 cm) diameter, ≥4.5 in. (11.5 cm) length, 2 in. (5 cm) clearance, cylindrical shape, and a smooth, nonslip surface.
2. An optimal hand-hold cut-out has the following approximate characteristics: ≥1.5 in. (3.8 cm) height, 4.5 in. (11.5 cm) length, semioval shape, ≥2 in. (5 cm) clearance, smooth nonslip surface, and ≥0.25 in. (0.60 cm) container thickness (e.g., double thickness cardboard).
3. An optimal container design has 16 in. (40 cm) frontal length, 12 in. (30 cm) height, and a smooth nonslip 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 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.
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.

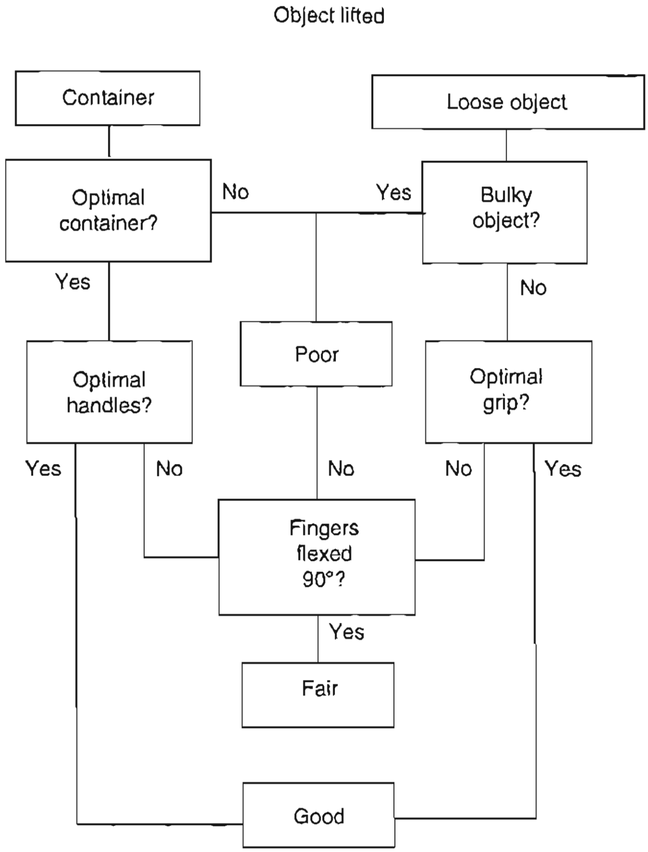

Figure 20.3 Decision tree for coupling quality.

20.5 Procedures

Prior to data collection, the analyst must decide (1) if the job should be analyzed as a single-task or multitask manual lifting job and (2) if significant control is required at the destination of the lift. This is necessary because the procedures differ, depending on the type of analysis required.

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

Table 20.7 Coupling Multiplier

	Coupling Multiplier	
Coupling Type	$V < 30$ in. (75 cm)	$V \geqq 30$ in. (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

multitask manual lifting job. A multitask analysis is more difficult to perform than a single-task analysis because additional data and computations are required. The multitask 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 multitask 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 multitask approach provides a reasonable method of assessing the overall physical demands. The multitask 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 multitask approach should be based on (1) the need for detailed information about all facets of the multitasked lifting job, (2) the need for accuracy and completeness of data regarding assessment of the physiological demands of the task, and (3) 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 the descent of the load. 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 lifting index (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: (1) data is collected at the worksite as described in Section 20.5.1; and, (2) the RWL and LI values are computed using the single-task or multitask analysis procedure described in Section 20.5.2.

20.5.1 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*). A job analysis worksheet, as shown in Figure 20.4 for single-task jobs or Figure 20.5 for multitask jobs, provides 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 that comprises the worker's complete job. For multitask jobs, data must be collected for each individual task.

20.5.2 Step 2: Single- and multitask procedures

20.5.2.1 Single-task procedure

20.5.2.1.1 Compute the recommended weight limit and lifting index: Calculate the RWL at the origin for each lift. For lifting tasks that require significant control at the destination, calculate the RWL at both the origin and the destination of the lift. The latter procedure is required if (1) the worker has to regrasp the load near the destination of the lift, (2) the worker has to momentarily hold the object at the destination, or (3) the worker has to position or guide the load at the destination. The purpose of calculating the RWL at

SINGLE-TASK JOB ANALYSIS WORKSHEET

DEPARTMENT	________	JOB DESCRIPTION	
JOB TITLE	________		________
ANALYST'S NAME	________		________
DATE	________		________

STEP 1. Measure and record task variables

Object Weight (lbs)		Hand Location (in)				Vertical Distance (in)	Asymmetric Angle (degrees)		Frequency Rate lifts/min	Duration (hrs)	Object Coupling
		Origin		Destination			Origin	Destination			
L (AVG)	L (MAX)	H	V	H	V	D	A	A	F		C

STEP 2. Determine the multipliers and compute the RWL's

		LC	x	HM	x	VM	x	DM	x	AM	x	FM	x	CM	=	LBS
Origin	RWL =	51	x		x		x		x		x		x		=	
Destination	RWL =	51	x		x		x		x		x		x		=	

STEP 3. Compute the lifting index

Origin Lifting Index $= \dfrac{\text{OBJECT WEIGHT (L)}}{\text{RWL}} = \underline{\qquad\qquad} = \boxed{}$

Destination Lifting index $= \dfrac{\text{OBJECT WEIGHT (L)}}{\text{RWL}} = \underline{\qquad\qquad} = \boxed{}$

Figure 20.4 Single-task analysis sheet.

both the origin and destination of the lift is to identify the most stressful location of the lift. Therefore, the lower of the RWL values at the origin or destination should be used to compute the LI for the task, since this value would represent the limiting set of conditions.

The assessment is completed on the single-task worksheet 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.

20.5.2.2 Multitask procedure

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.

20.5.2.2.1 Compute the frequency-independent recommended weight limits: Compute the frequency-independent recommended weight limits (FIRWL) value for each task by using the respective task variables and setting the frequency multiplier 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 task, the FIRWL must be computed at both the origin and the destination of the lift, as described above for a single-task analysis.

MULTITASK JOB ANALYSIS WORKSHEET

DEPARTMENT ____________ JOB DESCRIPTION
JOB TITLE ____________ ____________
ANALYST'S NAME ____________ ____________
DATE ____________ ____________

STEP 1. Measure and record task variable data

Task No	Object Weight (lbs)		Hand Location (in)				Vertical Distance (in)	Asymmetric Angle (degrees)		Frequency Rate lifts/min	Duration (hrs)	Object 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	x HM	x VM	x DM	x AM	x CM	FIRWL	x FM	STRWL	FILI = L/FIRWL	STLI = L/STRWL	New Task No.	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 20.5 Multitask analysis sheet.

20.5.2.2.2 *Compute the single-task recommended weight limit:* Compute the single-task recommended weight limit (STRWL) for each task by multiplying its FIRWL by its appropriate FM. 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, this value is helpful in determining the extent of excessive physical stress for an individual task.

20.5.2.2.3 *Compute the frequency-independent lifting index:* The frequency-independent lifting index FILI is computed for each task by dividing the maximum load weight (*L*) for that task by the 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.

20.5.2.2.4 *Compute the single-task lifting index:* The single-task lifting index (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 the average weight 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 (i.e., 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 the STLI value 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 that it may be possible to have a job in which all of the individual tasks have a STLI less than 1.0 and still be physically demanding due to the combined demands of the tasks. In cases where the FILI exceeds the STLI for any task, the maximum weight may represent a significant problem and careful evaluation is necessary.

20.5.2.2.5 Compute the composite lifting index: The assessment is completed on the multitask worksheet by determining the composite lifting index (CLI) for the overall job. The CLI is computed as follows:

1. Tasks are renumbered in order of decreasing physical stress, beginning with 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. CLI for the job is then computed according to the following formula:

$$\text{CLI} = \text{STLI}_1 + \sum \Delta\text{LI}$$

where:

$$\begin{aligned}\sum \Delta\text{LI} = &\left(\text{FILI}_2 \times \left(\frac{1}{\text{FM}_{1,2}} - \frac{1}{\text{FM}_1}\right)\right)\\ &+ \left(\text{FILI}_3 \times \left(\frac{1}{\text{FM}_{1,2,3}} - \frac{1}{\text{FM}_{1,2}}\right)\right)\\ &+ \left(\text{FILI}_4 \times \left(\frac{1}{\text{FM}_{1,2,3,4}} - \frac{1}{\text{FM}_{1,2,3}}\right)\right)\\ &\vdots\\ &+ \left(\text{FILI}_n \times \left(\frac{1}{\text{FM}_{1,2,3,4,\ldots,n}} - \frac{1}{\text{FM}_{1,2,3,\ldots,(n-1)}}\right)\right)\end{aligned}$$

Note that (1) the numbers in the subscripts refer to the new task numbers and (2) the FM values are determined from Table 20.5, based on the sum of the frequencies for the tasks listed in the subscripts.

The following example is provided to demonstrate this step of the multitask procedure. Assume that an analysis of a typical three-task job provided the results shown in Table 20.8.

To compute the CLI for this job, the tasks are renumbered in order of decreasing physical stress, beginning with the task with the greatest STLI down to the task with the smallest STLI. In this case, as shown in Table 20.8, the task numbers do not change. Next, the CLI is computed according to the formula shown above. The task with the greatest CLI

Table 20.8 Computations from Multitask Example

Task Number	Load Weight (L)	Task Frequency (F)	FIRWL	FM	STRWL	FILI	STLI	New Task
1	30	1	20	0.94	18.8	1.5	1.6	1
2	20	2	20	0.91	18.2	1.0	1.1	2
3	10	4	15	0.84	12.6	0.67	0.8	3

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 20.5, FM_1 is 0.94, $FM_{1,2}$ is 0.88, and $FM_{1,2,3}$ is 0.70. Finally, the $CLI = 1.6 + 1.0(1/0.88 - 1/0.94) + 0.67(1/0.70 - 1/0.88) = 1.6 + 0.07 + 0.20 = 1.9$. Note, that the FM values were based on the sum of the frequencies for the subscripts, the vertical height, and the duration of lifting.

20.6 Applying the equations

20.6.1 Using the RWL and LI to guide ergonomic design

The RWL and LI can be used to guide ergonomic design in several ways:

(1) 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) 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) 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) 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).

20.6.2 Rationale and limitations for LI

The NIOSH RWL equation and 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 et al. (1993). 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.

20.6.3 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, to the extent possible, 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 (i.e., lifting tasks that would exceed a LI of 1.0) without significantly increasing their risk of work-related injury above the baseline level (Waters et al., 1993). 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 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 (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.

20.6.4 Example problems

Two example problems are provided to demonstrate the proper application of the lifting equation and procedures. The procedures provide 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 also provide guidance in developing an ergonomic redesign strategy. Specifically, for each example, a job description, job analysis, hazard assessment, redesign suggestion, illustration, and completed worksheet are provided.

To help clarify the discussion of the example problems, and to provide a useful reference for determining the multiplier values, each of the six multipliers used in the equation have been reprinted in tabular form in Tables 20.1 through 20.5 and Table 20.7.

A series of general design/redesign suggestions for each job-related risk factor are provided in Table 20.9. These suggestions can be used to develop a practical ergonomic design/redesign strategy.

Table 20.9 General Design/Redesign Suggestions

If HM is less than 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 is less than 1.0	Raise or lower the origin or destination of the lift. Avoid lifting near the floor or above the shoulders.
If DM is less than 1.0	Reduce the vertical distance between the origin and the destination of the lift.
If AM is less than 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 is less than 1.0	Reduce the lifting frequency rate, reduce the lifting duration, or provide longer recovery periods (i.e., light work period).
If CM is less than 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 is less than at the origin	Eliminate the need for significant control of the object at the destination by redesigning the job or modifying the container or object characteristics.

20.6.5 Loading supply rolls, example 1

20.6.5.1 Job description

With both hands directly in front of the body, a worker lifts the core of a 35 lb roll of paper from a cart, and then shifts the roll in the hands and holds it by the sides to position it on a machine, as shown in Figure 20.6. 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.

20.6.5.2 Job analysis

The task variable data are measured and recorded on the job analysis worksheet (Figure 20.7). The vertical location of the hands is 27 in. at the origin and 10 in. at the destination. The horizontal location of the hands is 15 in. at the origin and 20 in. at the destination. The asymmetric angle is 0° at both the origin and the destination, and the frequency is 4 lifts/shift (i.e., less than 0.2 lifts/min for less than 1 h; see Table 20.5).

Using Table 20.6, the coupling is classified as poor because the worker must reposition the hands at the destination of the lift and they cannot flex the fingers to the desired 90° angle (e.g., hook grip). No asymmetric lifting is involved (i.e., $A=0$), 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 20.1 through 20.5 and 20.7). As shown in Figure 20.7, the RWL for this activity is 28.0 lbs at the origin and 18.1 lbs at the destination.

20.6.5.3 Hazard assessment

The weight to be lifted (35 lbs) is greater than the RWL at both the origin and destination of the lift (28.0 and 18.1 lbs, respectively). The LI at the origin is 35 lbs/28.0 lbs or 1.3, and the LI at the destination is 35 lbs/18.1 lbs or 1.9. These values indicate that this job is only slightly stressful at the origin, but moderately stressful at the destination of the lift.

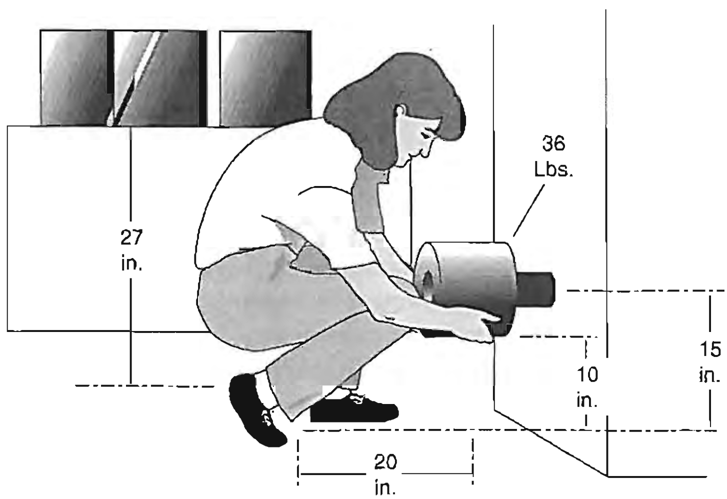

Figure 20.6 Loading supply rolls, example 1.

SINGLE-TASK JOB ANALYSIS WORKSHEET

DEPARTMENT	Shipping	JOB DESCRIPTION	Loading paper supply rolls
JOB TITLE	Packager		
ANALYST'S NAME			
DATE			

STEP 1. Measure and record task variables

Object Weight (lbs)		Hand Location (in)				Vertical Distance (in)	Asymmetric Angle (degrees)		Frequency Rate lifts/min	Duration (hrs)	Object Coupling
		Origin		Destination			Origin	Destination			
L (AVG)	L (MAX)	H	V	H	V	D	A	A	F		C
35	35	15	27	20	10	17	0	0	<.2	<1	Poor

STEP 2. Determine the multipliers and compute the RWL's

		LC	x	HM	x	VM	x	DM	x	AM	x	FM	x	CM	=	LBS
Origin	RWL =	51	x	0.67	x	0.98	x	0.93	x	1.00	x	1.00	x	0.9	=	28
Destination	RWL =	51	x	0.5	x	0.85	x	0.93	x	1.00	x	1.00	x	0.9	=	18.1

STEP 3. Compute the lifting index

Origin Lifting Index $= \frac{\text{OBJECT WEIGHT (L)}}{\text{RWL}} = \frac{35}{28} = 1.3$

Destination Lifting Index $= \frac{\text{OBJECT WEIGHT (L)}}{\text{RWL}} = \frac{35}{18.1} = 1.9$

Figure 20.7 Job analysis worksheet, example 1.

20.6.5.4 *Redesign suggestions*

The first choice for reducing the risk of injury for worker's 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 worksheet displayed in Figure 20.7 indicates that the multipliers with the smallest magnitude (i.e., 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 20.9, the following job modifications are suggested:

1. Bring the load closer to the worker by making the roll smaller so that the roll 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*) of the destination should be increased. Figure 20.8 shows that if *V* was increased to about 30 in., then VM would be increased from 0.85 to 1.0; the *H* value would be decreased from 20 to 15 in., which would increase HM from 0.50 to 0.67; the DM would be increased from 0.93 to 1.0. As shown in Figure 20.8, the final RWL would be increased from 18.1 to 30.8 lbs, and the LI at the destination would decrease from 1.9 to 1.1.

SINGLE-TASK JOB ANALYSIS WORKSHEET

DEPARTMENT Shipping
JOB TITLE Packager
ANALYST'S NAME
DATE

JOB DESCRIPTION
Loading paper supply rolls

Modified Example 1

STEP 1. Measure and record task variables

Object Weight (lbs)		Hand Location (in)				Vertical Distance (in)	Asymmetric Angle (degrees)		Frequency Rate lifts/min	Duration (hrs)	Object Coupling
		Origin		Destination			Origin	Destination			
L (AVG)	L (MAX)	H	V	H	V	D	A	A	F		C
35	35	15	27	20	30	3	0	0	<.2	<1	Poor

STEP 2. Determine the multipliers and compute the RWL's

		LC	x	HM	x	VM	x	DM	x	AM	x	FM	x	CM	=	LBS
Origin	RWL =	51	x	0.67	x	0.98	x	1.00	x	1.00	x	1.00	x	0.90	=	30.1
Destination	RWL =	51	x	0.50	x	0.85	x	0.93	x	1.00	x	1.00	x	0.90	=	30.8

STEP 3. Compute the lifting index

Origin Lifting index $= \frac{\text{OBJECT WEIGHT (L)}}{\text{RWL}} = \frac{35}{30.1} = 1.2$

Destination Lifting index $= \frac{\text{OBJECT WEIGHT (L)}}{\text{RWL}} = \frac{35}{30.8} = 1.1$

Figure 20.8 Modified job analysis worksheet, example 1.

In some cases, redesign may not be feasible. In these cases, 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.

20.6.5.5 *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.

20.6.6 *Dish-washing machine unloading, example 2*

20.6.6.1 *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 20.9. The trays are filled with assorted dishes (e.g., glasses, plates, and bowls) and silverware. The job takes between 45 min and 1 h to complete, and the lifting frequency rate averages 5 lifts/min. Workers usually twist to one side of their body to lift the trays (i.e., asymmetric lift) and then rotate to the other side of their body to lower the trays to the cart in one smooth continuous motion. The maximum amount of asymmetric twist varies between workers and within workers; however, there is usually equal twist to either side. During the lift the worker may

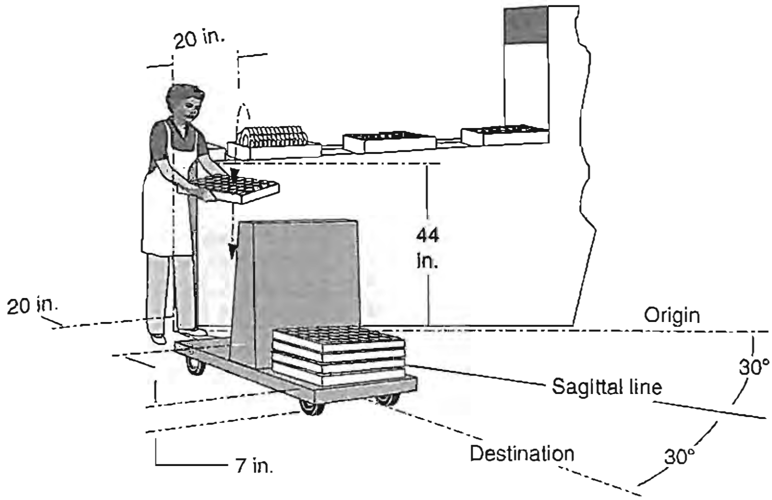

Figure 20.9 Dish-washing machine unloading, example 2.

take a step toward the cart. The trays have well-designed handhold cutouts and are made of lightweight materials.

20.6.6.2 *Job analysis*

The task variable data are measured and recorded on the job analysis worksheet (Figure 20.10). At the origin of the lift, the horizontal distance (H) is 20 in., the vertical distance (V) is 44 in., and the angle of asymmetry (A) is 30°. At the destination of the lift, H is 20 in., V is 7 in., and A is 30°. The trays normally weigh from 5 to 20 lbs, but for this example, assume that all of the trays weigh 20 lbs.

Using Table 20.6, the coupling is classified as "Good." Significant control is required at the destination of the lift. Using Table 20.5, the FM is determined to be 0.80. As shown in Figure 20.10, the RWL is 14.4 lbs at the origin and 13.3 lbs at the destination.

20.6.6.3 *Hazard assessment*

The weight to be lifted (20 lbs) is greater than the RWL at both the origin and destination of the lift (14.4 and 13.3 lbs, respectively). The LI at the origin is 20/14.4 or 1.4 and the LI at the destination is 1.5. These results indicate that this lifting task would be stressful for some workers.

20.6.6.4 *Redesign suggestions*

The worksheet shows that the smallest multipliers (i.e., 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 20.9, the following job modifications are suggested:

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

SINGLE-TASK JOB ANALYSIS WORKSHEET

DEPARTMENT Food Service
JOB TITLE Cafeteria Worker
ANALYST'S NAME
DATE

JOB DESCRIPTION
Unloading a dish-washing machine

Example 2

STEP 1. Measure and record task variables

Object Weight (lbs)		Hand Location (in)				Vertical Distance (in)	Asymmetric Angle (degrees)		Frequency Rate lifts/min	Duration (hrs)	Object Coupling
		Origin		Destination			Origin	Destination			
L (AVG)	L (MAX)	H	V	H	V	D	A	A	F		C
20	20	20	44	20	7	37	30	30	5	<1	Good

STEP 2. Determine the multipliers and compute the RWL's

		LC	x	HM	x	VM	x	DM	x	AM	x	FM	x	CM	=	LBS
Origin	RWL =	51	x	0.50	x	0.90	x	0.87	x	0.90	x	0.80	x	1.00	=	14.4
Destination	RWL =	51	x	0.50	x	0.83	x	0.87	x	0.90	x	0.80	x	1.00	=	13.3

STEP 3. Compute the lifting index

Origin Lifting index $= \dfrac{\text{OBJECT WEIGHT (L)}}{\text{RWL}} = \dfrac{20}{14.4} = 1.4$

Destination Lifting index $= \dfrac{\text{OBJECT WEIGHT (L)}}{\text{RWL}} = \dfrac{20}{13.3} = 1.5$

Figure 20.10 Job analysis worksheet, example 2.

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., then VM and DM are 1.0, as shown in the modified worksheet (Figure 20.11). Moreover, if the cart is moved so that the twist is eliminated, the AM can be increased from 0.90 to 1.00. As shown in Figure 20.11, with these redesign suggestions the RWL can be increased from 13.3 to 20.4 lbs, and the LI values are reduced to 1.0.

20.6.6.5 Comments

This analysis was based on a 1 h work session. If a subsequent work session begins before the appropriate recovery period has elapsed (i.e., 1.0 h), then the 8 h category would be used to compute the FM value.

20.7 Validation of the revised NIOSH lifting equation

Several studies have been conducted examining the effectiveness of the Revised NIOSH lifting equation (NLE) to identify jobs with increased risk of lifting-related low back disorders. Waters et al. (1999) conducted a cross-sectional study to investigate whether there was a significant relationship between risk of low back pain and exposure to jobs with various lifting index (LI) values. In the study, the 1 y prevalence of low back pain was determined for workers employed in jobs with varying LI values. Fifty jobs at four

SINGLE-TASK JOB ANALYSIS WORKSHEET

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 (lbs)		Hand Location (in)				Vertical Distance (in)	Asymmetric Angle (degrees)		Frequency Rate lifts/min	Duration (hrs)	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 RWL's

		LC	x	HM	x	VM	x	DM	x	AM	x	FM	x	CM	=	LBS
Origin	RWL =	51	x	0.50	x	1.00	x	1.00	x	1.00	x	0.80	x	1.00	=	20.4
Destination	RWL =	51	x	0.50	x	1.00	x	1.00	x	1.00	x	0.80	x	1.00	=	20.4

STEP 3. Compute the lifting index

Origin Lifting index $= \dfrac{\text{OBJECT WEIGHT (L)}}{\text{RWL}} = \dfrac{20}{20.4} =$ 1.00

Destination Lifting index $= \dfrac{\text{OBJECT WEIGHT (L)}}{\text{RWL}} = \dfrac{20}{20.4} =$ 1.00

Figure 20.11 Modified job analysis worksheet, example 2.

industrial sites were evaluated with the NLE. A symptom and occupational history questionnaire was administered to 204 people employed in those lifting jobs and 80 people employed in nonlifting jobs at the four sites. Jobs were categorized by exposure according to the following LI values: $LI = 0$ (unexposed), $0.0 < LI < 1.0$, $1.0 < LI < 2.0$, $2.0 < LI < 3.0$, and $LI > 3.0$. Regression analysis was used to determine whether there was a correlation between the lifting index and reported low back pain. The authors found that as the lifting index increased from 0.0 to 3.0, the odds of low back pain increased, with a peak and statistically significant odds ratio ($OR = 2.45$) occurring in the category of jobs with an LI value between 2.0 and 3.0. For the group of jobs with an LI value greater than 3.0, the OR value was lower ($OR = 1.63$) than for the 2.0–3.0 group and was not statistically different from the nonlifting group, but the authors explained that this finding was most likely due to a combination of worker selection, a survivor effect, and high turnover in the higher risk jobs. In a study of worker turnover rates on physically demanding jobs, Lavendar and Marras (1994) showed that high turnover rate was a good indicator of high risk for low back pain (LBP). In that study, the authors attributed lower than expected injury rates in jobs with high turnover to the "healthy worker effect." Based on the overall findings, Waters et al., (1999) concluded that, "Although LBP is a common disorder, the lifting index appears to be a useful indicator for determining the risk of low back pain caused by manual lifting."

In a study designed to investigate lifting-related musculoskeletal disorders in the metal processing industry in China, Xiao et al. (2004) used the revised NIOSH equation to analyze the risk factors for low back pain and to study the validity and feasibility of using the NLE in China. The NIOSH equation was used to evaluate lifting risk for 69 workers mainly involved in manual materials handling (Job A) and 51 machinery workers who worked in less demanding manual material handling (MMH) tasks (Job B). The prevalence of LBP lasting for more than a week due to lifting were 26.09% and 5.88% for Job A and B, respectively. The NIOSH LI was estimated to be 2.4 for Job A, and $0 < LI < 1$ for Job B. The authors concluded that the NIOSH equation is an important tool in assessing characteristics and risk factors of LBP for MMH tasks.

In another study, Marras et al. (1999) examined the relationship between low back disorders (LBD) and various risk factors for LBP due to manual lifting. One of the objectives of the study was to evaluate the validity and effectiveness of the revised NIOSH lifting equation (NLE) to correctly identify jobs with varying levels of risk of LBD, where job risk was defined according to historical records of LBD injuries. High-risk jobs were defined as jobs in which more than 12 LBDs were recorded per 100 exposed workers (mean of 22 injuries/100 exposed workers), medium-risk jobs were defined as jobs in which between 1 and 12 LBDs were recorded per 100 exposed workers, and low-risk jobs were defined as jobs in which no LBDs were recorded per 100 exposed workers. The results indicated that when the average horizontal distance was used, the NIOSH equation was predictive of risk of LBD, resulting in an odds ratios of 3.1 (95% CI, 2.6–3.8) for high-risk jobs compared to low-risk jobs. When the maximum horizontal distance was used, the odds ratio was increased to 4.3 for high-risk jobs compared to low-risk jobs.

In another study, conducted by Lee et al. in 1996, researchers examined whether the NLE was applicable for an Asian population. The application of the NIOSH equation for establishing weight limits for Korean workers was examined using the psychophysical method. The study population consisted of 53 male college students and 16 male field workers. The subjects were required to perform six different lifting tasks in the sagittal plane, at various lifting frequencies and heights, for 8 h. The RWLs for each lift were calculated using the NIOSH equation. The psychophysical method, in which subjects were allowed to adjust the weight of lift during a 20 min period, was also used to estimate the maximum acceptable weight of lift (MAWL) for each lifting task. Although students generally had larger body sizes than the worker population, workers were generally stronger than the students. Within each group, neither the frequency nor the vertical height of lift was significantly related to the differences between the NLE-based and psychophysical weight limits. The MAWLs of the workers were significantly higher than those of the students. Although this difference increased with increasing lift frequency, it was not sensitive to lift height. When the data were adjusted to represent the entire Korean young male population, no significant differences were observed between the NIOSH recommended weights of load and the adjusted MAWLs. Although the load constant of the NIOSH equation was 23 kg, that of the students was 20.24 kg and that of the workers was 25.05 kg. The authors conclude that the NIOSH weight limit equation is well suited for young, healthy Korean males.

Recently Hidalgo et al. (1995) conducted a study designed to evaluate the validity of the psychophysical, biomechanical, and physiological criteria used in establishing the NLE (Waters et al., 1993). The criteria used to develop the equation were cross-validated against the data published by different researchers in the scientific literature. Assessment of the 1991 NIOSH lifting equation indicated that there are differences between the NIOSH equation values and the psychophysical limits for some types of lifts and that the RWL likely would protect about 85% of the female population and 95% of the male population. The authors, however, noted that the 3.4 kN limit for compression on the lumbosacral joint may be too high to protect all workers and that the energy expenditure limits used in development of the RWL index can be sustained by 57%–99% of worker population when compared to the physiological limits based on previous fatigue studies. The authors concluded that the results of the cross-validation for psychophysical criterion confirmed the validity of assumptions made in the 1991 NIOSH revised lifting equation, but that the results of cross-validation for the biomechanical and physiological criteria were not in total agreement with the 1991 NIOSH model. They did not, however, actually evaluate whether the equation would protect workers or not in the study.

In 2003, Sesek et al. conducted a study designed to investigate the ability of the revised NLE to measure the risk of low back injury using employee health outcomes to identify high-risk manual lifting jobs. In addition to the NLE, a slightly modified version of the NLE was evaluated, in which some factors were removed from the equation for simplification. The authors found that, without the modifications, the revised NLE was able to predict back injuries with odds ratios of 2.1 (95% CI, 1.0–4.43) and 4.0 (95% CI, 1.5–10.3) for lifting indices of 1.0 and 3.0, respectively. They reported that simplifying the lifting equation by removing several variables did not significantly reduce the predictive performance of the equation. When the authors modified the equation, they found that the modified NLE was able to predict back injuries with odds ratios of 2.2 (95% CI, 1.0–4.6) and 5.3 (95% CI, 1.5–19.1) for lifting indices of 1.0 and 3.0, respectively. The authors concluded that these modifications to the NLE show promise for increasing both the usability and utility of the lifting equation.

An epidemiological study, conducted by Wang et al. (1998), evaluated the relation between low back discomfort ratings and use of the revised NLE to assess the risk of MMH tasks. In the study, the authors surveyed 97 MMH workers on site in 15 factories and designed a questionnaire to systematically collect job-related information. Approximately 90% of the workers had suffered various degrees of lower back discomfort, and 80% had sought medical treatment. The survey showed that 42 of the 97 jobs analyzed had a recommended weight limit of 0, which was attributed to either a horizontal distance or a lifting frequency that exceeded the bounds of the NIOSH lifting index. Based on the results of the study, the authors suggested that the limits for horizontal distance and maximum allowable frequency may be too stringent to accommodate many existing MMH jobs. The authors also reported that for the remaining 55 jobs, the significant positive correlation obtained between the lifting index and the severity of low back discomfort suggests that the lifting index is reliable in assessing the potential risk of low back injury in MMH. The authors concluded that their results provide useful information on the application of the NIOSH lifting guide to the assessment of low back pain.

In a study examining the effectiveness of a training course to provide instruction on the proper use of the NLE, Waters et al. (1998) trained a group of nonergonomists to use the revised NLE and then tested them 8 weeks post training to evaluate their knowledge in making the measurements needed to use the equation. Twenty-seven individuals from NIOSH participated in a 1 day training session on the use of the NLE. The participants were subsequently tested on a simulated lifting task 8 weeks later to determine their accuracy in measuring the variables. Analysis of the results indicated that (1) interobserver variability was small, especially for the most important factor (i.e., horizontal distance), (2) individuals can be trained to make measurements with sufficient accuracy to provide consistent recommended weight limit and lifting index values, and (3) measurement of the coupling and asymmetric variables were the least accurate and additional training should be provided to clarify these factors.

References

ASPH/NIOSH 1986, *Proposed National Strategies for the Prevention of Leading Work-Related Diseases and Injuries: Part 1*. Published by the Association of Schools of Public Health under a cooperative agreement with the National Institute for Occupational Safety and Health.

Hidalgo J., Genaidy A., Karwowski W., Christensen D., Huston R., and Stambough J. 1995, A cross-validation of the NIOSH limits for manual lifting. *Ergonomics*, 38 (12): 2455–2464.

Lavender, S.A. and Marras, W.S. 1994, The use of turnover rate as a passive surveillance indicator for potential low back disorders. *Ergonomics*, 37(6): 971–978.

Lee K.S., Park H.S., and Chun Y.H. 1996, The validity of the revised NIOSH weight limit in a Korean young male population: A psychophysical approach. *International Journal of Industrial Ergonomics*, 18 (2/3): 181–186.

Marras W., Fine L., Ferguson S., and Waters T. 1999, The effectiveness of commonly used lifting assessment methods to identify industrial jobs associated with elevated risk of low-back disorders. *Ergonomics*, 42 (1): 229–245.

NIOSH 1981, *Work Practices Guide for Manual Lifting*, NIOSH Technical Report No. 81–122, (U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health, Cincinnati, OH).

NIOSH 1991, *Scientific Support Documentation for the Revised 1991 NIOSH Lifting Equation: Technical Contract Reports, May 8, 1991,* (U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health, Cincinnati, OH). Available from the National Technical Information Service [NTIS No. PB-91-226-274].

Sesek R., Gilkey D., Drinkaus P., Bloswick D.S., and Herron R. 2003, Evaluation and quantification of manual materials handling risk factors. *International Journal of Occupational Safety and Ergonomics*, 9 (3): 271–287.

Wang M.J., Garg A., Chang Y.C., Shih Y.C., Yeh W.Y., and Lee C.L. 1998, The relationship between low back discomfort ratings and the NIOSH lifting index. *Human Factors and Ergonomics*, 40 (3): 509–515.

Waters T.R., Baron S.L., and Kemmlert K. 1998, Accuracy of measurements for the revised NIOSH lifting equation. National Institute for Occupational Safety and Health. *Applied Ergonomics*, 29 (6): 433–438.

Waters T.R., Putz-Anderson V., Garg A., and Fine L.J. 1993, Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics*, 36 (7): 749–776.

Waters T.R., Putz-Anderson, and Garg A. 1994, Applications manual for the revised NIOSH lifting equation. National Institute for Occupational Safety and Health, Technical Report. DHHS (NIOSH) Pub. No. 94-110. Available from the National Technical Information Service (NTIS). NTIS document number PB94-176930 (1-800-553-NTIS).

Waters, T.R., Baron, S.L., Piacitelli, L.A., Anderson, V.P., Skov, T., Haring-Sweeney, M., Wall, D.K., and Fine, L.J. 1999, Evaluation of the revised NIOSH lifting equation: A cross-sectional epidemiologic study. *Spine*, 24 (4): 386–394.

Xiao G.B., Lei L., Dempsey P., Ma Z.H., and Liang Y.X. 2004, Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi. Study on lifting-related musculoskeletal disorders among workers in metal processing, 22 (2): 81–85.

Biomechanics *in* Ergonomics

SECOND EDITION

Edited by

Shrawan Kumar

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **Informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3

International Standard Book Number-13: 978-0-8493-7908-6 (Hardcover)

Library of Congress Cataloging-in-Publication Data

Biomechanics in ergonomics / edited by Shrawan Kumar. -- 2nd ed.
p. ; cm.
"A CRC title."
Includes bibliographical references and index.
ISBN-13: 978-0-8493-7908-6 (hardcover : alk. paper)
ISBN-10: 0-8493-7908-3 (hardcover : alk. paper)
1. Human engineering. 2. Biomechanics. 3. Tissues—Mechanical properties. I. Kumar, Shrawan. II. Title.

TA166.B535 2007
620.8'2--dc22 2007021668

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com