APPENDIX I

ERGONOMICS, 1993, VOL. 36, NO. 7, 749–776

Rapid Communication

Revised NIOSH equation for the design and evaluation of manual lifting tasks

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Keywords: Low back pain; Prevention and control;
Evaluation methodology; Lifting.

In 1985, the National Institute for Occupational Safety and Health (NIOSH) convened an *ad hoc* committee of experts who reviewed the current literature on lifting, recommend criteria for defining lifting capacity, and in 1991 developed a revised lifting equation. Subsequently, NIOSH developed the documentation for the equation and played a prominent role in recommending methods for interpreting the results of the equation. The 1991 equation reflects new findings and provides methods for evaluating asymmetrical lifting tasks, lifts of objects with less than optimal hand–container couplings, and also provides guidelines for a larger range of work durations and lifting frequencies than the 1981 equation. This paper provides the basis for selecting the three criteria (biomechanical, physiological, and psychophysical) that were used to define the 1991 equation, and describes the derivation of the individual components (Putz-Anderson and Waters 1991). The paper also describes the lifting index (LI), an index of relative physical stress, that can be used to identify hazardous lifting tasks. Although the 1991 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. NIOSH believes that the revised 1991 lifting equation is more likely than the 1981 equation to protect most workers.

1. Introduction

The National Institute for Occupational Safety and Health (NIOSH) first developed an equation in 1981 to assist safety and health practitioners evaluate lifting demands in the sagittal plane (NIOSH 1981). The lifting equation was widely used by occupational health practitioners because it provided an empirical method for computing a weight limit for manual lifting. This limit proved useful for identifying certain lifting jobs that posed a risk to the musculoskeletal system for developing lifting-related low back pain (Liles and Mahajan 1985). Because the 1981 equation could only be applied to a limited number of lifting tasks, namely sagittal lifting tasks, the 1981 equation was revised and expanded in 1991 to apply to a larger percentage of lifting tasks.

The 1991 lifting equation reflects new findings, provides methods for evaluating asymmetrical lifting tasks, objects with less than optimal hand–container couplings, and offers new procedures for evaluating a larger range of work durations and lifting

frequencies than the earlier equation. The objective of both equations is to prevent or reduce the occurrence of lifting-related low back pain (LBP) among workers. An additional benefit of this equation is the potential to reduce other musculoskeletal disorders or injuries associated with some lifting tasks such as shoulder or arm pain (Chaffin *et al.* 1976).

Three criteria (biomechanical, physiological, and psychophysical) were used to define the components of the original and revised lifting equation (Putz-Anderson and Waters 1991). The present document describes the rationale for selecting these criteria and demonstrates how they were used to determine the equation values. The document also discusses the limitations of the lifting equation and the use of a lifting index for identifying hazardous jobs.

The limitations of the lifting equation are a result of the small number of scientific studies related to some key hypotheses, the typical uncertainties with the conclusions of most of the scientific studies, and the inability of current clinical methods to characterize accurately the specific pathoanatomic cause of most cases of work-related low back pain or other work-related musculoskeletal disorders. In general, when faced with uncertainties in the data, the 1991 committee chose the most conservative (i.e., most protective) approach.

1.1. *Occupational factors associated with LBP*

Manual handling and lifting are a major cause of work-related LBP and impairment. LBP also can occur by direct trauma, a single exertion ('overexertion'), or potentially as the result of multiple exertions ('repetitive trauma') (Pope *et al.* 1991). Several other work-related factors including pushing or pulling activities, extreme postures such as forward flexion, and cyclic loading (whole body vibration) are also associated with development of LBP and impairment.

Low back pain also is common in work environments where no lifting or manual handling activities occur, such as work in a predominantly sitting posture (Lawrence 1955). In addition, evidence exists that work-related psychological stress and lifestyle factors also may increase the risk of LBP and the subsequent risk of prolonged impairment or desirability (Bigos *et al.* 1986, Frymoyer *et al.* 1980). Moreover, the revised lifting equation accounts for only a limited number of lifting-related task factors (seven in all), and therefore does not include adjustments for many of these other important factors. Furthermore, the lifting equation applies only to lifting tasks in which two hands are used to move the load.

Although the lifetime prevalence of LBP in the general population is as high as 70%, work-related LBP comprise only a subset of all cases of LBP in the population (Frymoyer *et al.* 1983, National Safety Council 1990). In general, the fraction of LBP which is work-related is difficult to determine in many work settings. Brown (1973) and Magora (1974) indicated that specific lifting or bending episodes were related to only about one-third of the work-related cases of LBP. Thus, even the prevention of all LBP due to lifting will not prevent all episodes of work-related pain, or prevent the common non-work-related episodes of LBP.

1.2. *Background*

The past 15 years of research on lifting-related LBP and manual lifting have produced three findings with substantial scientific support: (1) manual lifting poses a risk of LBP

Table 1. Criteria used to develop the lifting equations.

Discipline	Design criterion	Cut-off value
Biomechanical	Maximum disc compression force	3·4 kN (770 lbs)
Physiological	Maximum energy expenditure	2·2–4·7 kcal/min‡
Psychophysical	Maximum acceptable weight	Acceptable to 75% of female workers and about 99% of male workers

Note:
‡ Since the energy expenditure limit for a specific task depends on the vertical height of the lift and the duration of continuous lifting, task-specific criteria are presented in table 3.

to many workers; (2) LBP is more likely to occur when workers lift loads that exceed their physical capacities; and (3) the physical capacities of workers vary substantially.[1]

1.3. *Development and history of the 1991 lifting equation*
The 1991 lifting equation is patterned after the 1981 equation in its development, format, and interpretation (NIOSH 1981). Both versions are the product of *ad hoc* NIOSH committees of experts who reviewed the current literature on lifting, met, discussed the existing criteria for defining lifting capacity, and developed a lifting equation. When the 1991 equation was developed, however, NIOSH staff prepared the documentation for the lifting equation and played a prominent role in recommending methods for interpreting the results of the equation.[2]

The 1991 committee's deliberations represented a unique compromise between empirical findings and expert judgment, particularly when results were contradictory, inconsistent, or simply limited. The main product of the 1991 committee was the revised NIOSH lifting equation that appears in Appendix A.

2. Basis for selecting the criteria

Both the 1981 and 1991 lifting equations are based on three criteria derived from the scientific literature and the combined judgment of experts from the fields of biomechanics, psychophysics, and work physiology (table 1). In general, the criteria chosen by the NIOSH *ad hoc* committees (1981 and 1991) were used as a basis to develop an equation for determining a recommended weight limit for a specific task. The recommended weight limit for a task represents a load value 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.

Several criteria were used to develop the equation because each lifting task imposes different biomechanical and physiological requirements on the worker. As a result, the limiting factor or criteria in each lifting task may vary. The biomechanical criterion limits the effects of lumbosacral stress, which is most important in *infrequent lifting tasks*. The physiological criterion limits the metabolic stress and fatigue associ-

[1] Physical capacities include static and dynamic strength as well as various anatomical and physiological capacities such as flexibility, cardiovascular (aerobic) capacity, and tissue tolerance and recovery capacities.
[2] 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 (see NTIS 1991).

Table 2. Individual criterion and equation comparisons.

	Estimated criterion-based weight loads (kg)			1991 equation
Lifting* examples	Biomechanical[a]	Physiological[b]	Psychophysical[c]	RWL
Task 1	24	> 24	14	10
Task 2	> 24	> 24	13	13
Task 3	20	7	8	6
Task 4	24	6	12	4

Notes:

* each of the four tasks are described in the Appendix, Part C;

[a] based on 350 kg disc compressioin force;

[b] based on 3·1 kcal/min for Tasks 1, 2, and 4, and 2·2 kcal/min for Task 3;

[c] based on maximum weight of lift acceptable to 75% of females; Tasks 1–3 are based on Snook and Ciriello (1991) and Task 4 is based on Ayoub *et al.* 1978.

ated with *repetitive lifting tasks*.[3] The psychophysical criterion limits the workload based on the workers' perception of their lifting capability, a measure applicable to *nearly all lifting tasks*, except high-frequency lifting (above 6 lifts per min).

Ideally, the criteria chosen to establish the lifting equation should be based on a scientifically supported, quantitative relationship between the criteria and the actual risk of lifting-related musculoskeletal injury or LBP. Since this approach is not currently feasible, the lifting criteria, for the most part, are based on secondary or surrogate measures of injury or LBP. For each of these secondary measures, there is a variable amount of scientific or semi-quantitative evidence to indicate that the chosen lifting criteria can reliably predict the risk of lifting-related LBP.

Because each criterion focuses on different aspects of lifting stressors, recommended load weights that meet one criterion may not meet the others. For example, metabolic data suggest that it is more efficient to lift heavier weights less frequently that to lift lighter weights more frequently; however, biomechanical studies suggest that the load should be minimized by lifting lighter weights more frequently to reduce muscle and vertebral stresses. Furthermore when lifting from the floor, results from psychophysical studies suggest that workers can typically lift heavier loads than those estimated from biomechanical or physiological studies. Hence, load recommendations for lifting often vary depending on which criteria are applied.

Because each criterion may provide a unique load limit for a specified lifting task, the 1991 committee designed the lifting equation to provide, in general, the most conservative load limit allowed by any individual criterion.

An example of this approach is provided in table 2. The details of how the values were determined is provided in the Appendix , Part C. In table 2, estimated load limits are presented for four sample lifting tasks that are based solely on each criterion. The last column shows the 1991 equation values, which as noted, are lower than values based on the individual criterion. As discussed in section 7, the lower recommended weight limit values are primarily attributed to the multiplicative nature of the equation.

Differences between the physiologically-based weights and the recommended weight limit (RWL) values vary depending on how many factors are drawn into the

[3] The effects of local muscle fatigue are discussed in section 4.

equation (i.e., frequency, asymmetry, vertical factor, etc., as required to analyse the lifting task).

3. Biomechanical criterion

Three issues underlie the 1991 committee's selection of the biomechanical criterion for the NIOSH lifting equation: (1) the choice of joint between the L5 and S1 vertebral segments (L5/S1) as the site of greatest lumbar stress during lifting; (2) the choice of compressive force as the critical stress vector; and (3) the decision to select 3·4 kN as the compressive force that defines an increased risk of low-back injury.

3.1. *Site of greatest lumbar stress during lifting*

An established biomechanical hypothesis is that the capacity for infrequent lifts is a combined function of the individual's muscle strength and the strength of various body structures, particularly the lumbar spine. Studies have confirmed that lifting under certain conditions is limited more by the stresses on the lumbar spine than by limitations of strength (Chaffin and Moulis 1969). Moreover, when manual lifting is modelled, large moments are created in the trunk area, especially when the load cannot be held close to the body (Chaffin and Andersson 1984). Because the disc between L5 and S1 vertebrae has the potential to incur the greatest moment in lifting and is also one of the most vulnerable tissues to force-induced injuries, many investigators have sought to obtain estimates of the biomechanical stresses for the L5/S1 disc (Chaffin 1969, Tichauer 1971, Krusen *et al.* 1965, Garg *et al.* 1982, Anderson *et al.* 1985).

3.2. *Compressive force as the critical stress vector*

During lifting, three types of stress vectors are transmitted through the spinal musculoskeletal tissues to the L5/S1: compressive force, shear force, and torsional force. The relative importance of each stress vector is not well understood. Disc compression is believed to be largely responsible for vertebral end-plate fracture, disc herniation, and resulting nerve root irritation (Chaffin and Andersson 1984). Moreover, large compression forces at the L5/S1 spinal disc can be produced by muscular exertion, especially during lifting (Chaffin and Andersson 1984). Herrin *et al.* (1986) concluded that 'the biomechanical criterion of maximal back compression appears to be a good predictor not only of risk of low-back incidents but of overexertion injuries in general'. Because of the clinical interest in disc diseases and their causes, numerous studies have been conducted to assess the compressive strength of the lumbar vertebral bodies and intervertebral discs. As a result of these and similar findings, and the accompanying uncertainty regarding the effects of shear and torsional stresses on lumbar tissue, disc compressive force was chosen by the 1991 committee as the critical stress vector underlying the biomechanical criterion used to develop the lifting equation.

3.3. *Determining the compressive force that defines increased risk*

Because *in vivo* measures of compressive force are difficult, if not impossible, to undertake with current technology, the 1991 committee reviewed data from cross-sectional field studies that provided estimates of compressive forces generated by lifting tasks and subsequent injuries. Ultimately, prospective studies are needed to identify compressive force levels at the L5/S1 joint that increase risk of low-back injury.

3.3.1. *Cadaver data*: These data have been used to evaluate the strength of lumbar specimens to withstand applied compressive force. With data collected for 307 lumbar segments from various studies, Jager and Luttman (1989) determined the compressive strength of the lumbar segments and found a mean value of 4·4 kN with a standard deviation of 1·88 kN. These results suggest that if the data were normally distributed, approximately 30% of the lumbar segments had an ultimate compressive strength of less than 3·4 kN and 16% had an ultimate compressive strength of less than 2·5 kN (1 standard deviation less than the mean). Since the distribution pattern of data was not provided, however, we cannot accurately predict the percentage of lumbar segments with maximum compressive strength values less than 3·4 kN.

Brinckmann *et al.* (1988) found maximum compressive strength values for vertebral segments ranging from 2·1 to 9·6 kN. The data indicate that fewer than 21% of the cadaver spinal segments fractured or experienced end-plate failure at loads below 3·4 kN, whereas only one segment failed at loads below 2·5 kN.

Cadaver studies generally show large variability in the measured compressive strength of the spine within and between studies. This may be due to declines in lumbar strength with age, bone mineral content, and degenerative changes (Hansson and Roos 1981). Typically, the data showed that as the compressive force on the spine increased, there was an increase in the percentage of vertebra which were damaged. For a small fraction of vertebra, damage occurred at compressive force levels as low as 2·5 kN. One of the limitations of the vertebra compressive strength data is uncertainty whether compression injury to vertebra in cadaver studies is a reliable predictor of the risk of lifting-related low back pain, impairment, or disability.

3.3.2. *Biomechanical models*: These models have been used to estimate *in vivo* compressive forces on the L5/S1 intervertebral joint and disc. Chaffin (1969) developed one of the first widely applied biomechanical models, based on a refinement of the Morris *et al.* (1961) static sagittal-plane (SSP) model. Chaffin's model included only two sources of internal forces for resisting the external load moment of lifting: (1) the action of the extensor erector spinae muscle; and (2) the stabilizing force provided by the pressure of the abdominal cavity. The model predicted compressive forces for the lumbosacral disc. These predicted forces were based on the weight of the load and its distance from the base of the spine. More complex biomechanical models have been developed, but each model requires specific assumptions and simplifications (Gracovetsky and Farfan 1986, McGill and Norman 1986, and Bean *et al.* 1988). In general, each model provides somewhat different estimates of spinal compressive forces.

In the future, compressive forces may be predicted more accurately by biomechanical models that consider the dynamic components of lifting, possible antagonistic muscle forces, passive tissue loading, and the three dimensional loading characteristics of the muscles. The dynamic component of lifting may be especially important for understanding the cause of back injury. Specifically, a number of investigators have reported that lifts with high acceleration components produce greater predicted compressive forces on the spine than lifts in which the acceleration is assumed to be zero. The estimated compressive values for the dynamic models ranged from 19% to 200% greater than the static model predictions (Garg *et al.* 1982, Leskinen *et al.* 1983, Freivalds 1984, McGill and Norman 1985, Bush-Joseph *et al.* 1988, Marras and Sommerich 1991a, 1991b). Because the 1991 committee lacked data linking the pre-

dicted dynamic compressive forces to the observed incidence of lifting-related LBP, the committee chose the simpler and older model to develop the force criterion for disc compression.

Four studies have reported a direct relationship between lifting-related LBP and predicted static compressive force on the L5/S1 disc (Herrin *et al.* 1986, Bringham and Garg 1983, Anderson 1983, Chaffin and Park 1973). In a retrospective study, Herrin *et al.* (1986) evaluated 55 industrial jobs using a biomechanical model. The study sample consisted of 2934 potentially stressful manual materials handling tasks. The investigators traced the medical reports of 6912 incumbent workers employed in these jobs. For jobs with predicted compressive forces between 4·5 kN (1000 lb) and 6·8 kN (1500 lb), the rate of back problems was more than 1·5[4] times greater than that for jobs with compressive forces below 4·5 kN.

In another study, Bringham and Garg (1983) reported that jobs in which workers experienced muscular strains had an average estimated compressive force of 5·34 kN. Furthermore, jobs in which workers had disc injuries had an average estimated compressive force of 7·97 kN. In a similar study, Anderson (1983) reported that when males performed lifting jobs with a predicted compressive force exceeding 3·4 kN, they had a 40% higher incidence rate of LBP than did males employed in jobs with predicted compressive forces below that level. Chaffin and Park conducted a similar study relating compressive force to injury incidence, as cited in the *Work Practices Guide for Manual Lifting* (NIOSH 1981). Although their study cannot be used to determine the difference in injury incidence rates for jobs with compressive forces above and below 3·4 kN, they suggested that (1) the LBP incidence for repetitive lifting tasks was less than 5% when the predicted compressive force on the L5/S1 joint was below 2·5 Kn, and (2) the incidence rate increased to more than 10% when the predicted compressive force exceeded 4·5 kN.

3.4. *Biomechanical conclusions*

The 1991 committee recognized the limitations and uncertainties of biomechanical modelling of the lumbar spine. Even the most complex models only provide estimates of the *relative* magnitude of the compressive force rather than provide reliable estimates of *absolute* force levels. In general, the committee based its final determination for the biomechanical criterion (i.e., 3·4 kN) on data from field studies in which some quantitative data were provided linking compressive force estimates with the incidence of low-back disorders. Given the limitations and variability of the data linking compressive force and injury incidence, the 1991 NIOSH committee decided to maintain the 1981 biomechanical criterion of 3·4 kN compressive force for its revision of the 1991 lifting equation.

3.5. *NIOSH perspective*

The NIOSH perspective independent of the 1991 committee, is that a maximum compressive force of 3·4 kN on the L5/S1 vertebrae may not protect the entire workforce for two principal reasons: (1) data from some of the workplace studies suggest that even in survivor workplace populations, jobs with compressive forces below

[4] In the published article, the incidence rate of back problems for jobs with maximum back compression between 4·5 kN and 6·8 kN was incorrectly reported as 109/200,000 h or 18 times the rate for jobs with disc compression below 4·5 kN. The actual rate was 9/200,000 h, or 1·5 times the rate for jobs with maximum disc compression force below 4·5 kN (based on personal correspondence with the NIOSH project director for this study).

3·4 kN were associated with an increase in the risk of back injuries; and (2) data from laboratory cadaver studies indicate that some members of the general population may suffer end-plate failure when performing lifts that create compressive forces below 3·4 kN.

4. Physiological criterion

The 1991 committee selected the physiological criterion of energy expenditure to limit loads for *repetitive lifting*. A main reason is that dynamic activities such as walking, load carrying, and repeated load lifting use more muscle groups than infrequent lifting tasks. Because the aerobic energy demands of dynamic lifting tasks require multiple muscle groups to move both the load and the body, large energy expenditures are required to supply the muscles with sufficient oxygen for contraction. Without oxygen to release adenosine triphosphate (ATP), prolonged dynamic activity cannot be sustained. When the metabolic demands of dynamic and sustained activity exceed the energy producing capacity of a worker, muscle contraction is affected and whole body fatigue is usually experienced (Astrand and Rodahl 1986).

Since it is assumed that the lifts are made within a 3 s time frame, local muscle fatigue should not develop. Moreover, local muscle fatigue that could develop from high-frequency repetitive lifting or from heavy workloads is limited by the values in the frequency multiplier table that are provided with the equation (Rodgers *et al.* 1991). Heavy workload is defined as muscular exertion > 70% of maximum voluntary contraction.

Although there is limited empirical data demonstrating that whole body fatigue increases the risk of musculoskeletal injury, the 1991 committee recognized that repetitive lifting tasks could easily exceed a worker's normal energy capacities, causing a premature decrease in strength and increasing the likelihood of injury (Lehmann 1958, Brown 1972, Garg and Saxena 1979). To control excessive fatigue, a baseline maximum aerobic capacity was established to determine maximum expenditure for repetitive lifting tasks. A criteria designed to limit excessive whole body fatigue, however, does not necessarily protect against the potentially hazardous *cumulative effects* of repetitive lifting.

Three important decisions underlie the 1991 committee's selection of the baseline maximum aerobic capacity and resultant limits for task specific energy expenditures: (1) the *choice* of 9·5 kcal/min as the baseline measure of maximum aerobic lifting capacity used to determine the energy expenditure limits for repetitive lifting tasks; (2) the *choice* of the percentage (70%) of baseline maximum aerobic capacity used to establish an energy expenditure limit for lifts that predominantly require arm work (i.e., lifts above 75 cm or 30 inches); and (3) the *choice* of three percentages (50%, 40%, and 33%) of baseline maximum aerobic lifting capacity to establish energy expenditure limits for lifting tasks lasting 1 h, 1 to 2 h, and 2 to 8 h, respectively.

4.1. *Rationale for the baseline maximum aerobic capacity*

Aerobic capacity varies widely among workers according to age, sex, physical fitness, etc. (Astrand and Rodahl 1986). Average maximum aerobic capacities, assessed using treadmill procedures, have been reported for 20-year-old conditioned male workers to be as high as 20 kcal/min and as low as 7·3 kcal/min for 55-year-old female workers (Astrand and Rodahl 1986, Coleman and Burford 1971). In general, older workers have a lower capacity than younger workers, and female workers have a lower capacity

Table 3. Task-specific energy expenditure limits for frequent lifting (kcal/min).

Lift location (V) cm (in.)	Duration of lifting		
	< 1 h	1–2 h	2–8 h
$V \leq 75$ (30)	4·7	3·7	3·1
$V > 75$ (30)	3·3	2·7	2·2

than male workers. To a moderate extent, physical conditioning also may increase an individual's aerobic capacity to perform repetitive lifting (Astrand and Rodahl 1986).

In order to determine energy expenditure limits for repetitive lifting as shown in table 3, the 1991 committee selected a baseline maximum aerobic capacity that could be adjusted to accommodate different lifting conditions. Most existing measures of maximum aerobic capacity were obtained from subjects using a treadmill test. According to Petrofsky and Lind (1978a, 1978b), however, the maximum aerobic capacity measures obtained using a treadmill test overestimate the maximum aerobic capacity available for performing repetitive lifting tasks (Rodgers *et al.* 1991). As a result, the 1991 committee reduced the baseline aerobic capacity from the 1981 value of 10·5 kcal/min to 9·5 kcal/min to adjust for the difference between treadmill data and data collected from manual lifting studies. (A value of 9·5 kcal/min is equivalent to a capacity of 4000 kcal per day for a 420 min period of work.) The 1991 committee selected this value as the assumed mean aerobic *lifting* capacity of the average (50th percentile) 40-year old female worker (Eastman Kodak 1986). This baseline aerobic capacity was subsequently adjusted for various lifting locations and durations of repetitive lifting (table 3 and Appendix B).

Although the 1991 committee chose a physiological criterion that represented the capacity of a 50th percentile female, rather than the capacity of the 75th percentile female, they were not necessarily endorsing a 50th percentile criterion. The committee recognized that the multiplicative nature of the equation would provide a final weight limit that would be lower than a weight limit generated solely on the basis of the 50th percentile female physiological criterion. Their decision seems to be appropriate considering the effects of the other factors in the equation. For example, the RWL values for the repetitive tasks in table 2 (Tasks 3 and 4) are lower than the weight limits derived solely from the physiological criterion.

The committee's raionale for choosing the physiological criterion also was based on the belief that: (1) workers often can vary their lifting pace; and (2) vary their activities to reduce accumulated fatigue (Rodgers *et al.* 1991). Hence, in situations in which workers are unable to exercise some control over their rate of work, the recommended weight limits for repetitive lifting jobs could be excessive for workers who are not well conditioned, leading to both local and systemic fatigue

Further research on paced lifting is needed to determine if the revised lifting equation is suitable for such conditions.

4.2. *Rationale for task-specific energy expenditure limits*

4.2.1. *Adjustments for vertical lifting locations*: Whole-body work is required when lifts are below waist level (i.e., when they involve the leg, low back, shoulder, and arm muscles, such as when $V <$ about 75 cm or 30 in), but lifts above waist level require primarily the shoulder and arm muscles. Since an arm lift requires less muscular

activity than a whole body lift, the maximum energy *expenditure* also is less for an arm lift. However, the maximum aerobic *capacity* for arm work is also lower (about 70%) than that attained for whole-body aerobic activity (Astrand and Rodahl 1986, Sharp *et al.* 1988). Hence, both work capacity and energy expenditure are reduced for arm lifts. As a result, the 1991 committee recommended a 30% reduction in the energy expenditure limit of 9·5 kcal/min for lifting acts involving primarily the upper body (i.e. $V > 75$ cm or 30 in).

4.2.2. *Adjustments for durations of repetitive lifting*: To avoid high levels of whole-body fatigue, the 1991 committee concluded that the energy expenditure for repetitive lifting must also be based on limits that apply to the duration of the task. Most studies and reviews recommend work limits of approximately 33% of the maximum aerobic capacity for repetitive lifting tasks that are longer than two hours (Asfour *et al.* 1988, Karwowski and Yates 1986, Legg and Pateman 1984, Mital 1984a, Williams *et al.* 1982).

To adjust energy expenditure values for the aerobic demands posed by different durations of repetitive lifting tasks, the 1991 committee selected the following limits: (1) Repetitive lifting tasks *lasting 1 h or less* should not require workers to exceed 50% of the 9·5 kcal/min baseline maximum aerobic capacity value; (2) repetitive lifting tasks *lasting 1 to 2 h* should not require workers to exceed 40% of the 9·5 k/cal/min baseline; and (3) repetitive lifting tasks *lasting 2 to 8 h* should not require workers to exceed 33% of the 9·5 kcal/min baseline. The 1991 committee did not provide energy expenditure limits for tasks lasting more than 8 h.

4.3. *Physiological conclusions*

The goal of the 1991 committee was to prevent systemic or aerobic fatigue and possibly local muscle fatigue that might increase the risk of lifting-related low back pain for a *majority of physically fit workers* engaged in repetitive manual lifting. As a result, the 1991 committee computed the energy expenditure limits displayed in table 3, based on a maximum aerobic lifting capacity of 9·5 kcal/min. Further research is needed to validate the energy expenditure limits for the lifting conditions in table 3.

4.4. *NIOSH perspective*

The NIOSH perspective, independent of the 1991 committee, is that a baseline aerobic lifting capacity of 9·5 kcal/min limit may be too high, particularly for older workers, since it could fail to *prevent fatigue even in some healthy workers*. Some studies indicate that both younger and older workers may have maximum aerobic capacities below 9·5 kcal/min. In general, the relationship between fatigue and risk of back injury is not sufficiently established to determine precisely the level of excess risk for jobs that exceed the energy expenditure limits in table 3. Additionally, the physiological criteria may not prevent dysfunction or damage to the tissues of the low back from the repetitive nature of lifting even if whole body fatigue is successfully prevented.

5. Psychophysical criterion

The psychophysical criterion is based on data defining workers' strength and capacity to perform manual lifting at different frequencies for different durations. The psychophysical criterion is defined directly by measures of maximum-acceptable-weight-of-lift and indirectly from studies measuring isometric strength. Although strength is an important determinant of the capability of an individual to perform an infrequent or

occasional lift, 'capability (maximum-acceptable-weight-of-lift) appears to be substantially lower than isometric or isotonic strength maxima' (Ayoub and Mital 1989).

The critical issues for the psychophysical criterion are as follows: (1) the rationale of the 1991 committee for choosing a criterion acceptable to 75% of female workers; and (2) the rationale for using maximum-acceptable-weight-of-lift and strength to determine recommended weight limits.

5.1. *Rationale for choosing the acceptability criterion*

The maximum-acceptable-weight-of-lift is the amount of weight a person chooses to lift under given conditions for a defined period. In measurements of maximum-acceptable-weight-of-lift, workers typically are asked to 'work as hard as you can without straining yourself, or without becoming unusually tired, weakened, overheated, or out of breath' (Snook and Ciriello 1991). The maximum-acceptable-weight-of-lift provides an empirical measure that appears to integrate both biomechanical and physiological sources of stress for all but certain high-frequency lifting tasks (Karwowski and Ayoub 1984). Unlike maximum strength measures, which define what a person can do on a single attempt, the maximum acceptable measure defines what a person can do repeatedly for an extended period without excessive fatigue, which may lead to lifting-related low back pain.

5.2. *Relating maximum-acceptable-weight-of-lift to low back pain*

The 1991 committee selected the psychophysical criterion based on several studies that relate the incidence and severity of lifting-related low back pain to the extent to which lifting demands are judged acceptable to experienced workers. Specifically, injuries increased for lifting tasks rated acceptable by less than 75% to 90% of the workers (Snook 1978, Herrin *et al.* 1986). Snook (1978) summarized his findings as follows:

> The results revealed that approximately one-quarter of policyholder jobs involve manual handling tasks that are acceptable to less than 75% of the workers; however, one-half of the low back injuries were associated with these jobs. This indicates that a worker is three times more susceptible to low back injury if performing a manual handling task that is acceptable to less than 75% of the working population. This also indicates that, at best, two out of every three low back injuries associated with heavy manual handling tasks can be prevented if the tasks are designed to fit at least 75% of the population. The third injury will occur anyway, regardless of the job.

Several investigators reported that workers who have experienced back injury typically rate the physical effort in their jobs as greater than workers on similar jobs who have not had back injury (Magora 1970, Dehlin *et al.* 1976). Herrin *et al.* (1986) also reported that the rate of medical back incidents (i.e., sprains, strains, degenerative disc disease, and other ill-defined pain) increased significantly for jobs with strength demands that exceeded the lifting capability (i.e. the maximum acceptable weight) of 90% of the exposed workers.

The 1991 committee selected the psychophysical criterion to ensure that the job demands posed by manual lifting would not exceed the acceptable lifting capacity of about 99% of male workers and 75% of female workers—or 90% of the working population (if one assumes a working population that is 50% male and female).

Table 4. Psychophysical and equation-based weight loads (kg).

	Female per cent acceptability		1991 equation
Lifting tasks*	75%	90%	RWL
Small H, small V H = 37 cm V = 78·5 cm	18	16	15
Small H, large V H = 37 cm V = 154 cm	16	14	12
Large H, small V H = 58 cm V = 78·5 cm	17	14	10
Large H, small V H = 58 cm V = 154 cm	12	10	8

Note:
* Assuming *FM*, *DM*, *AM*, and *CM* are idealized (i.e., = 1);
Snook and Ciriello, 1991.

5.3. *Psychophysical conclusions*

The psychophysical approach provides a method to estimate the combined effects of biomechanical and physiological stressors of manual lifting. Because it relies on self-reporting from subjects, the perceived 'acceptable' limit may differ from the actual 'safe' limit. Even though there is a relationship between the 'acceptable' and the 'safe' limit, the psychophysical approach may not be equally valid for all combinations of task variables. For example, most data indicate that the psychophysical approach overestimates workers' capacity for high-frequency lifting (> 6 lifts/min) (Ciriello and Snook 1983, Asfour *et al.* 1985, Karwowski and Yates 1986). The psychophysical approach also may overestimate capacity for lifting lasting more than about 1 h (Mital 1983). Fernandez and Ayoub (1987) and Ciriello *et al.* (1990), however, have recently refuted this concept. Fernandez and Ayoub found that the MAWL did not decrease significantly over time. Ciriello *et al.* (1990) also found that psychophysical methods, when properly administered, do not overestimate lifting capacity in tasks lasting up to four hours.

5.4. *NIOSH perspective*

The NIOSH perspective, independent of the 1991 committee, is that the psychophysical criterion of 'acceptability to 75% of female workers' does not treat men and women equally. Nevertheless as shown in tables 4 and 5, the 1991 equation yields recommended weight limits (RWLs) that are lower than weights acceptable to at least 90% of females. Hence, the 1991 equation provides a more equitable assessment of potentially hazardous lifting tasks for women than would be apparent from the psychophysical criterion alone (i.e., acceptable to 75% of females). For example, table 4 displays load weights (kg) from Snook and Ciriello (1991) for a series of typical lifting tasks involving variations in the horizontal (H) and vertical (V) factors. Also supplied are the corresponding RWLs computed from the 1991 equation. All four of the examples produced RWLs that were lower in weight than comparable psychophysical values acceptable to 90% of the females. In general, the values provided by the 1991

Table 5. Comparison of recommended weight limits with Snook and Ciriello's maximum acceptable weight limit for 90% of female workers.*

Vertical displacement of lift (cm)	Horizontal distance of load from body (cm)	Vertical starting height of lift (cm)	Recommended weight limit (kg) RWL	Snook and Ciriello's 1991 maximum acceptable weight limit for 90% of female workers (kg)
		Floor–knuckle		
25	37	26	10·0	11
	45	26	8·2	9
	58	26	6·3	9
51	37	12·5	8·7	11
	45	12·5	7·1	9
	58	12·5	5·5	8
76	42	0	7·1	9
	50	0	5·9	8
	63	0	4·7	7
		Knuckle–shoulder		
25	37	92	11·1	12
	45	92	9·2	10
	58	92	7·1	10
51	37	78·5	10·6	10
	45	78·5	8·7	9
	58	78·5	6·7	9
76	37	66	10·0	9
	45	66	8·3	9
	58	66	6·3	9
		Shoulder–reach		
25	37	154	8·9	10
	45	154	7·3	8
	58	154	5·6	8
51	37	141	8·5	9
	45	141	7·0	7
	58	141	5·4	7
76	37	128	8·7	8
	45	128	7·1	7
	58	128	5·5	6

Note:
* Evaluated at a task frequency (F) of 1 lift/min.

equation are consistent with or lower than the average lifting weights for task conditions reported by Snook and Ciriello. Those weight limits were acceptable to 90% of the females (table 5).

6. Derivation of the equation components

Following the selection of the individual criterion, the 1991 committee developed the revised lifting equation (Appendix A). This section presents the derivation of the revised lifting equation and explains how the criteria were used to develop the individual components. The discussion addresses the standard lifting location, the load constant, and the derivation of the mathematical expressions (multipliers). Each

component of the revised lifting equation (Appendix A) was designed to satisfy the lifting criteria and was based, to the extent possible, on the results of quantitative research studies. Where the data were conflicting, however, decisions affecting the multipliers were based on a consensus of the 1991 committee. In most cases, the final decisions represented the most conservative (i.e. the most protective) estimates of lifting capacity.

The development of the lifting equation required that: (1) a standard lifting location be defined; (2) a load constant for the equation be established; and (3) the mathematical expressions for each factor be derived.

6.1. *Defining the standard lifting location*

The standard lifting location serves as the three-dimensional reference point for evaluating the worker's lifting posture. The standard lifting location for the 1981 equation was defined as a vertical height of 75 cm from the floor and a horizontal distance of 15 cm from the mid-point between the ankles. The 1991 equation continues to use a vertical height of 75 cm for the standard reference location, as supported by recent data (Ruhmann and Schmidtke 1989). However, the horizontal displacement factor was increased from 15 to 25 cm for the 1991 equation. This increase reflects recent findings that showed 25 cm as the minimum horizontal distance most often used by workers lifting loads that did not interfere with front of the body (Garg and Badger 1986, Garg 1986).

6.2. *Establishing the load constant*

The load constant (23 kg or 51 lbs) refers to the maximum recommended weight for lifting at the standard lifting location under optimal conditions (i.e. sagittal position, occasional lifting, good couplings, ≤ 25 cm vertical displacement, etc.). Selection of the load constant is based on the psychophysical and biomechanical criteria. The 1991 committee estimated that lifting a load equivalent to the load constant under ideal conditions (i.e., where all of the factors are equal to 1·0) would be acceptable to 75% of female workers and about 90% of male workers and that the disc compression force resulting from such a lift would be less than 3·4 kN.

For the revised equation, the load constant was reduced from 40 to 23 kg. This reduction was partly driven by the need to increase the 1981 minimum horizontal displacement from 15 to 25 cm for the 1991 equation, as noted above. The revised load constant is 17 kg less than that for 1981; but at the revised minimum horizontal displacement of 25 cm, the 23 kg load constant represents only a 1 kg reduction from the 1981 equation when adjusted for revised horizontal distance. This 1 kg reduction reflects recent data reported by Snook and Ciriello (1991) indicating that the maximum acceptable weight limit for female workers is lower than the capacity that was reported in 1978 (Snook 1978).

Although the 23 kg load constant was based on the maximum acceptable weight limit for 75% of female workers, the recommended weight limits are likely to be acceptable to at least 90% of female workers when the revised load constant is applied in the lifting equation. This conclusion is based on a comparison with the Snook and Ciriello (1991) study (table 5).

6.3. *Deriving mathematical expressions*

The multipliers for the revised lifting equation refer to the six coefficients (mathematical expressions) used to reduce the load constant to compensate for characteristics of the lifting task which are different from the standard or optimal conditions

(i.e., sagittal position, occasional lifting, good couplings, ≤ 25 cm vertical displacement, etc.). These conditions or factors were identified in one or more epidemiologic studies of manual lifting (Chaffin and Park 1973, Snook 1978, Frymoyer *et al.* 1983, Bigos *et al.* 1986). Each of the six multipliers should satisfy all three of the lifting criteria presented in table 1. In most cases, the multipliers represent the most conservative estimate of lifting capacity for each individual lifting factor.

The six multipliers (coefficients) were derived from a series of adjustments (iterations) in which the revised coefficients were used to generate predicted loads. These loads were then compared with empirically derived lifting values from the previously cited psychophysical lifting studies. The rationale for each of the six multipliers is briefly reviewed in the following subsections.

6.3.1. *Horizontal multiplier*: Biomechanical and psychophysical studies indicate that with increasing horizontal distance of the load from the spine, the predicted disc compression force increases and the maximum acceptable weight limit decreases (Snook 1978, Chaffin and Andersson 1984, Garg 1986). The axial compression stress applied to the spine during lifting is generally proportional to the horizontal distance of the load from the spine. For example, both the load and the flexion moment (the product of the load and the horizontal distance from the spinal axis) are important in determining the axial compression stresses on the lumbar spine (Schultz *et al.* 1982, Chaffin and Andersson 1984). Furthermore, psychophysical data consistently indicate that as the load is moved horizontally from the spine, the amount of weight a person is willing to lift decreases proportionately (Snook 1978, Ayoub *et al.* 1978, Garg and Badger 1986, Snook and Ciriello 1991).

To satisfy the lifting criteria, the horizontal multiplier (HM) was determined as follows:

$$HM = (25/H) \tag{1}$$

where H = the horizontal distance in centimetres

$$HM = (10/H) \tag{2}$$

where H = the horizontal distance in inches

6.3.2. *Vertical multiplier*: Biomechanical studies suggest an increased lumbar stress for lifting loads near the floor (Chaffin 1969, Bean *et al.* 1988). Epidemiologic studies indicate that lifting from near the floor is associated with a large percentage of low-back injuries attributable to lifting (Snook 1978, Punnett *et al.* 1991). Physiological studies indicate that lifting from near the floor requires a significantly greater energy expenditure than lifting from greater heights (Fredrick 1959, Garg *et al.* 1978). Although no direct empirical data exist to provide a specific adjustment value for lifting near the floor, the 1991 committee recommended that the vertical factor provide at least a 22·5% decrease in the allowable weight for lifts originating near the floor. The rationale for reduction of loads to be lifted above 75 cm from the floor is based on empirical data from psychophysical studies indicating that a worker's maximum-acceptable-weight-of-lift decreases as the vertical height of lift (V) increases above 75 cm (Snook 1978, Ayoub *et al.* 1978, Snook and Ciriello 1991). The 1991 committee chose a discount value of 22·5% to decrease the allowable weight for lifts at shoulder level (150 cm, or 60 in) and for lifts at floor level, resulting in the following vertical multiplier:

$$VM = (1 - 0{\cdot}003|V - 75|) \tag{3}$$

where V = vertical height in centimetres

$$VM = (1 - 0{\cdot}0075|V - 30|) \tag{4}$$

where V = vertical height in inches

6.3.3. *Distance multiplier*: The results of psychophysical studies suggest an approximate 15% decrease in maximum-acceptable-weight-of-lift when the total distance moved is near the maximum (e.g., lifts originating near the floor and ending above the shoulder (Garg *et al.* 1978, Snook 1978, Snook and Ciriello 1991). Also, results of physiological studies indicate a significant increase in physiological demand as the vertical distance of the lift increases (Aquilano 1968, Khalil *et al.* 1985). Finally, for lifts in which the total distance moved is < 25 cm (< 10 in), the physiological demand is not significantly increased, and therefore the multiplier should be held constant. As a result, the distance multiplier (DM) was established by the 1991 committee as follows:

$$DM = (0{\cdot}82 + (4{\cdot}5/D)) \tag{5}$$

where D = the total distance moved in centimetres

$$DM = (0{\cdot}82 + (1{\cdot}8/D)) \tag{6}$$

where D = the total distance moved in inches

6.3.4. *Asymmetric multiplier*: To date, only a few studies provide data on the relationship between asymmetric lifting (i.e., lifting loads away from the sagittal plane) to maximum acceptable lifting capacities. Of the limited number of psychophysical studies available, all have reported a decrease in maximum acceptable weight (8% to 22%) and a decrease in isometric lifting strength (39%) for asymmetric lifting tasks of 90 degrees compared with symmetric lifting tasks (Garg and Badger 1986, Mital and Fard 1986, Garg and Banaag 1988). The results from biomechanical studies also support a significant decrease in the allowable weight for asymmetric lifting jobs (Bean *et al.* 1988).

Therefore, the 1991 committee recommended that the asymmetric multiplier be established so that the allowable weight of lift be reduced by about 30% for lifts involving asymmetric twists of 90 degrees. The asymmetric multiplier (AM) was established by the 1991 committee as follows:

$$AM = (1 - (0{\cdot}0032A)) \tag{7}$$

where A = the angle between the sagittal plane and the plane of asymmetry. (The asymmetry plane is defined as the vertical plane that intersects the midpoint between the ankles and the midpoint between the knuckles at the asymmetric location.)

6.3.5. *Coupling multiplier*: Loads equipped with appropriate couplings or handles facilitate lifting and reduce the possibility of dropping the load. Psychophysical studies that investigated the effects of handles on maximum-acceptable-weight-of-lift suggested that lifting capacity was decreased in lifting tasks involving containers without good handles (Garg and Saxena 1980, Smith and Jiang 1984, Drury *et al.* 1989). Although these studies did not agree precisely on the degree of reduction in lifting

Table 6. Coupling multiplier.

Couplings	$V < 75$ cm (30 in)	$V \geq 75$ cm (30 in)
	Coupling multipliers	
Good	1·00	1·00
Fair	0·95	1·00
Poor	0·90	0·90

capacity, most concluded that the reduction should be in the range of about 7% to 11% for containers without handles. The coupling multipliers are displayed in table 6.

Considering the quality of the data and the difficulty in judging the quality of the coupling, the consensus of the 1991 committee was that the penalty for a poor coupling should not exceed 10%. Hence, the container coupling multiplier (*CM*) was defined as follows:

$$CM = 1{\cdot}0,\ 0{\cdot}95,\ \text{or}\ 0{\cdot}90 \tag{8}$$

depending on the vertical height of the lift and the quality of the couplings. Coupling quality was categorized as good, fair, or poor. Height was categorized as ≤ 75 cm (30 in) or > 75 cm.

6.3.6. *Frequency multiplier*: For the 1991 lifting equation, the appropriate frequency multiplier is obtained from a table (table 7) rather than from a mathematical

Table 7. Frequency multiplier (*FM*).

Frequency lifts/min	Work duration					
	≤ 1 h		≤ 2 h		≤ 8 h	
	$V < 75$	$V \geq 75$	$V < 75$	$V \geq 75$	$V < 75$	$V \geq 75$
0·2	1·00	1·00	0·95	0·95	0·85	0·85
0·5	0·97	0·97	0·92	0·92	0·81	0·81
1	0·94	0·94	0·88	0·88	0·75	0·75
2	0·91	0·91	0·84	0·84	0·65	0·65
3	0·88	0·88	0·79	0·79	0·55	0·55
4	0·84	0·84	0·72	0·72	0·45	0·45
5	0·80	0·80	0·60	0·60	0·35	0·35
6	0·75	0·75	0·50	0·50	0·27	0·27
7	0·70	0·70	0·42	0·42	0·22	0·22
8	0·60	0·60	0·35	0·35	0·18	0·18
9	0·52	0·52	0·30	0·30	0·00	0·15
10	0·45	0·45	0·26	0·26	0·00	0·13
11	0·41	0·41	0·00	0·23	0·00	0·00
12	0·37	0·37	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

Note:
‡ values of V are in cm; 75 cm = 30 in.

expression and table, as was the case in the 1981 lifting equation (i.e., in 1981, the $FM = 1 - [F/F_{max}]$, where FM = the frequency multiplier, F = task frequency rate, and F_{max} = maximum frequency as obtained from a table).

The frequency multipliers in table 7 are based on two sets of data. For lifting *frequencies up to 4 lifts/min*, psychophysical data from Snook and Ciriello (1991) were used to develop the frequency multiplier (FM) values.[5] These FM values are shown in the upper portion of table 7 (all cells in the first six rows).

For lifting *frequencies above 4 lifts/min*, the frequency multipliers values, which are displayed in table 7, row 5 and below, were determined from a three-step process using the energy expenditure prediction equations developed by Garg (1976) (Garg *et al.* 1978) (see Appendix, Part D).

The first step used Garg's empirically-derived linear regression equations to predict the energy demands of lifting tasks for *frequencies above 4 lifts/min*. The equations include terms for gender, weight of load, frequency of lifts, and the worker's body weight. Two equations were used, one for lifts below the waist and one for lifts above the waist, namely: a stoop-lift equation and an arm-lift equation (Rodgers *et al.* 1991: 34–35). Assuming a body weight of 130 lbs for a woman, Garg in an iterative approach determined the combinations of frequencies of lifts and weights of loads that would yield energy expenditure values equivalent to those in table 3. For all calculations, the most energy efficient lifting posture was assumed since workers tend to use the most efficient method.

In the second step, frequency multipliers were then generated from these intermediate load weights that would provide Recommended Weight Limits equivalent to the load weights determined from the first step.

For the third step, the committee reviewed and adjusted the frequency multipliers in table 7 to ensure that: (1) the frequency multipliers for lifts below 30 inches would not exceed those for lifts of 30 inches or above; and (2) that the transition zone between the psychophysical- and physiological-derived frequency multipliers (i.e., 4 lifts/min) provided continuous values. In general, the frequency multiplier values in table 7 meet the energy criteria provided in table 3 with a few exceptions. The results of the analysis are provided in greater detail in Rodgers (1991: 35–37).

The committee did note in their analysis, however, that the energy expenditure for repetitive squat lifts may exceed the energy expenditure limits listed in table 3, row 1. This finding is also consistent with different studies showing that the energy demands for squat postures are greater than for stoop postures (Frederik 1959, Garg and Herrin 1979, Kumar 1984).

The committee concluded that the frequency multipliers provide a close approximation of observed and predicted effects of lifting frequency on acceptable workloads for lifting (Rodgers *et al.* 1991: 37).

From the NIOSH perspective, it is possible that obese workers may exceed the energy expenditure criteria for lifts from below the waist. In addition, there are some circumstances in which local muscle fatigue may occur even though whole body fatigue has not occurred. This is most likely in situations involving lifting at high rates for longer than 15 min, or prolonged use of awkward postures, such as constant bending.

[5] Snook and Ciriello's (1991) data provide recommended weight limits for repetitive manual lifting tasks performed under a wide variety of conditions (different heights, locations, and frequencies).

7. Identifying hazardous lifting jobs with the lifting index

A key concept of the 1981 lifting equation is that the risk of lifting-related low back pain increases as the demands of the lifting task increase (Chaffin and Park 1973, Snook 1978, Herrin *et al.* 1986). Based on this concept, the 1981 lifting equation was used to define two points: the action limit and the maximum permissible limit (which is three times the action limit). For job assessment purposes, lifting jobs that required workers to lift loads below the action limit were considered to pose little risk of lifting-related low back pain for most workers. Lifting jobs that required workers to lift loads between the action limit and the maximum permissible limit likely pose increased risk for some workers but not for others. And lifting jobs that required workers to lift loads above the maximum permissible limit were considered to pose a significant risk of lifting-related low back pain for many workers.

The 1991 equation is also based on the concept that the risk of lifting-related low back pain increases as the demands of the lifting task increase. Rather than using a three-stage decision matrix, however, as was used with the 1981 equation, a single lifting index (LI) was proposed for the 1991 equation. Specifically, the LI is the ratio of the load lifted to the recommended weight limit. The lifting index (LI) is similar in concept to Ayoub's job severity index (JSI) and Chaffin's lifting strength rating (LSR) (Ayoub *et al.* 1978 and Chaffin 1974). Each of these indices encompass the notion that the risk of injury increases as the load or job demands exceeds some baseline capacity of the worker. This capacity may be estimated from a lifting equation, or from estimates of worker's strength, as assessed by various psychophysical tests and regression models.

The lifting index (LI) provides a simple method for comparing the lifting demands associated with different lifting tasks in which the load weights vary and the recommended weight limits (RWL) vary. In theory, the magnitude of the LI may be used as a gauge to estimate the percentage of the workforce that is likely to be at risk for developing lifting-related low back pain. The shape of the risk function, however, is not known. Thus it is not possible to quantify the precise degree of risk associated with increments in the lifting index. In a similar manner, there is uncertainty about whether a lifting index of one is a reliable boundary for differentiating between an increase in risk and no increase in risk for some fraction of the working population. The previous discussion of the criteria underlying the lifting equation and of the equation multipliers highlight the assumptions and uncertainties in the scientific studies and the theoretical models which have related lifting to low back injuries. However, these uncertainties do not all point in the same direction. Some support the belief that a lifting index of one will place a substantial fraction of the work force at an increased risk of low back pain. Others support the belief that most of the work force can work safely above a lifting index of one.

Three of the most important limitations of the equation are the following:

(1) A significant part of the equation is based on psychophysical laboratory studies. Since these data are obtained from workers' judgment of perceived lifting stress, psychophysical data may reveal more about a worker's tolerance to stress than of impending low back pain.
(2) The physiological criterion is based on restricting energy expenditures to avoid whole body fatigue. The criterion, however, does not address the potential risk associated with the cumulative effects of repetitive lifting, which may be independent of the level of whole body fatigue.

(3) If the three criteria for the equation were considered individually, they would probably not be protective of all workers.

A main tenet of our approach, however, is that the multiplicative nature of the equation has provided a final equation that is more likely to protect healthy workers than each individual criterion. Specifically, when several factors deviate from the ideal (i.e., standard lift location), the decline in the predicted value obtained from a multiplicative model for most lifts depends on the product of several factors; this substantially reduces the RWL. Based on individual parameters, the multiplicative model defines discrete regions where no lifting is allowed no matter how ideal the other parameters are. For example, if the horizontal factor exceeds 25 inches, the multiplier is zero, resulting in a computed RWL value of zero. This means that no weight should be lifted for this task condition.

Despite the limitations of the research studies and inherent uncertainties in relying on expert judgment, it is likely that lifting tasks with a lifting index > 1 pose an increased risk for lifting-related low back pain for some fraction of the workforce. Therefore, 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.

Some members of the 1991 committee believe that worker selection criteria based on research studies, empirical observations, or theoretical considerations such as job-related strength testing or aerobic capacity testing can accurately identify workers who can perform lifting tasks with a lifting index > 1 without an increased risk of a work-related injury (Chaffin and Andersson 1984, Ayoub and Mital 1989). These members agree, however, that many workers will be at elevated risk if the lifting index exceeds 3·0. Additionally, some members of the 1991 committee believe that the 'informal' selection of workers which occurs in many jobs that require repetitive lifting tasks lead to a workforce that can work above a lifting index of 1·0 without substantial risk of low back injuries above the baseline rate of injury.

8. Limitations of the 1991 lifting equation

8.1. *General limitations*

The lifting equation is a specialized risk assessment tool. As with any specialized tool, its application is limited to those conditions for which it was designed. Specifically, the lifting equation was designed to meet select lifting-related criteria that encompasses biomechanical, work physiology, and psychophysical assumptions and data, identified above. To the extent that a given lifting task accurately reflects these underlying conditions and criteria, this lifting equation may be appropriately applied. The following list identifies a set of work conditions in which the application of the lifting equation would either under-or-over estimate the risk of low back pain or injury. Each of the following task limitations also highlight research topics in need of further research to extend the application of the lifting equation to a greater range of real world lifting tasks.

1. The 1991 lifting equation assumes that manual handling activities other than lifting are minimal and do not require significant energy expenditure, especially when repetitive lifting tasks are performed. Examples of non-lifting tasks include holding, pushing, pulling, carrying, walking, and climbing. If such non-lifting activities are common, measures of workers' energy expenditures and heart rate may be required to assess the metabolic demands of the different tasks.

2. The 1991 lifting equation does not include task factors to account for unpredicted conditions, such as unexpectedly heavy loads, slips, or falls. Additional biomechanical analyses may be required to assess the physical stress on joints that occur from traumatic incidents. Moreover, if the environment is unfavourable (e.g., temperature or humidity significantly outside the range of 19° to 26°C [66° to 79°F] or 35% to 50%, respectively) independent metabolic assessments would be needed to gauge the effects of these variables on heart rate and energy consumption.

3. The 1991 lifting equation was not designed to assess tasks involving one-handed lifting, lifting while seated or kneeling, lifting in a constrained work space, lifting people, lifting of extremely hot, cold, or contaminated objects, lifting of wheel barrels, shoveling, or high-speed lifting (i.e., lifting that is not performed within a 2–4 s time frame). For such task conditions, independent and task specific biomechanical, metabolic, and psychophysical assessments are needed.

4. The 1991 lifting equation assumes that the worker/floor surface coupling provides at least a 0·4 (preferably 0·5) coefficient of static friction between the shoe sole and the working surface. An adequate worker/floor surface coupling is necessary when lifting to provide a firm footing and to control accidents and injuries resulting from foot slippage. A 0·4 to 0·5 coefficient of static friction is comparable to the friction found between a smooth, dry floor and the sole of a clean, dry leather work shoe (nonslip type). Independent biomechanical modelling may be used to account for variations in the coefficient of friction.

5. The 1991 lifting equation assumes that lifting and lowering tasks have the same level of risk for low back injuries (i.e., that lifting a box from the floor to a table is equally as hazardous as lowering the same box from a table to the floor). This assumption may not be true if the worker actually drops or guides the box to the floor rather than lowers all the way to the floor. Independent psychophysical assessments need to be undertaken to assess worker capacity for various lowering conditions.

In conclusions, the lifting equation is only one tool in a comprehensive effort to prevent work-related low back pain and disability. Lifting is only one of the causes of work-related low back pain and disability. There are many other causes which have been hypothesized or established as factors including 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.

8.2. *The need for validation*

All methods need validation. For the 1991 lifting equation, validation will require an extensive collaborative effort. Appropriate studies must be designed and conducted to determine whether the methods presented here effectively reduce the morbidity associated with manual materials handling, particularly two-handed lifting tasks.

9. Summary and conclusions

The 1991 revised lifting equation was prepared as a methodological tool for safety and health practitioners who must evaluate the lifting demands of a wider range of manual handling jobs than contained in the 1981 *Work Practices Guide for Manual Lifting* (NIOSH 1981). The equation was designed to assist in the identification of ergonomic solutions for reducing the physical stresses associated with manual lifting by identifying the features of the lifting task that contribute the most to the hazard for low back injuries.

Three criteria (biomechanical, physiological, and psychophysical) were used to define the limiting components for the revised lifting equation. This approach was adopted because we found that a single criterion would likely fail to protect healthy workers from back injury for many common types of lifting tasks. In general, the 1991 committee believed that the combination of using a multiplicative model and the practice of using the most conservative criterion or data values when faced with uncertainty served to provide a final lifting equation which is more likely to protect healthy workers for a wider variety of lifting tasks than methods which rely on only a single task factor (e.g., weight) or single criterion (e.g., intradiscal pressure).

NIOSH believes that the revised 1991 lifting equation is more likely than the 1981 equation to protect most workers. There are two main reasons for this: (1) the 1991 equation is applicable to a wider variety of lifting jobs than the 1981 equation because of the addition of the asymmetric and coupling multipliers, ultimately affecting more lifting jobs and workers; and (2) the recommended weight limits computed using the 1991 equation are generally lower than the maximum acceptable weight limits reported by Snook and Ciriello (1991). Because of the uncertainties in both the existing scientific studies and theoretical models, further research is needed to assess the magnitude of risk for lifting-related LBP and its association with the lifting index.

Acknowledgements

The authors gratefully acknowledge the technical assistance of the 1991 committee members in developing the revised equation: M. M. Ayoub, Ph.D.; Donald Chaffin, Ph.D.; Colin Drury, Ph. D.; Arun Garg, Ph.D.; and Suzanne Rodgers, Ph.D. We also wish to thank Gunnar Andersson, M.D., Ph.D., Jerome Congleton, Ph.D., Stephan Konz, Ph.D., David Olson, Ph.D., Stephen Simon, Ph.D., and Stover Snook, Ph.D., for their valuable contributions in the review of the manuscript. Special thanks to Anne C. Hamilton, Division of Standards Development and Technology Transfer, for her careful editorial review. Finally, special appreciation is extended to Janet C. Haartz, Ph.D., Director, Division of Biomedical and Behavioral Science, for her leadership, support, and technical guidance.

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Received 2 September 1992.
Revision accepted 4 November 1992.

Appendices

A. Calculation for recommended weight limit

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

Recommended weight limit

Component		*Metric*	*US customary*
LC = load constant	=	23 kg	51 lbs
HM = horizontal multiplier	=	$(25/H)$	$(10/H)$
VM = vertical multiplier	=	$(1-(0{\cdot}003\lvert V-75\rvert))$	$(1-(0{\cdot}0075\lvert V-30\rvert))$
DM = distance multiplier	=	$(0{\cdot}82+(4{\cdot}5/D))$	$(0{\cdot}82+(1{\cdot}8/D))$
AM = asymmetric multiplier	=	$(1-(0{\cdot}0032A))$	$(1-(0{\cdot}0032A))$
FM = frequency multiplier (from table 7)			
CM = coupling multiplier (from table 6)			

where:

H = horizontal distance of hands from midpoint between the ankles. Measure at the origin and the destination of the lift (cm or in).

V = vertical distance 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 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 h; ≤ 2 h; or ≤ 8 h assuming appropriate recovery allowances (see table 7).

B. Calculation for energy expenditure limit

1. For lifts above 75 cm (30 in), multiply the baseline aerobic work capacity (9·5 kcal/min)[6] by 0·7.
2. For lifting duration up to 1 h, multiply the value obtained in step 1 above by 0·5; for duration up to 2 h, multiply by 0·4; and, for duration between 2 and 8 h, multiply by 0·33.

For example, the energy expenditure limit for 8 h of lifting above the waist (75 cm) would be $9{\cdot}5 \times 0{\cdot}7 \times 0{\cdot}33$ or 2·2 kcal/min, as shown in table 3.

C. Comparison of criterion-based load weights

Task descriptions

Task 1 [floor–knuckle]	$H = 42$ cm, $V = 0$ cm, $D = 76$ cm, $F = 1/30$ min
Task 2 [knuckle–shoulder]	$H = 37$ cm, $V = 66$ cm, $D = 76$ cm, $F = 1/30$ min
Task 3 [shoulder–reach]	$H = 37$ cm, $V = 127$ cm, $D = 76$ cm, $F = 4$/min
Task 4 [floor–shoulder]	$H = 42$ cm, $V = 0$ cm, $D = 152$ cm, $F = 4$/min

Common factors

- 25th percentile female with a height of 160 cm and weight of 57 kg (Eastman Kodak 1986);
- semi-squat or stoop lifting posture;
- box size of $40 \times 34 \times 14$ cm [LWH];
- good couplings;
- sagittal plane lifts only (no asymmetry);
- lifting duration of 4 h.

To simplify the analyses, the following assumptions were made to correspond to the Snook and Ciriello (1991) data:

- vertical displacement (D) was assumed to be 76 cm (30 inches);
- box width (W) of 34 cm was chosen to correspond to Snooks' box width of 34 cm;
- lifting duration of 4 h was chosen to correspond to Snook and Ciriello (1991);
- horizontal distance (H) was estimated from box width (W) and vertical lift height (V) using the following equations:

$$H = 20 + W/2 \quad \text{for } V > 75 \text{ cm (30 inches)};$$
$$H = 25 + W/2 \quad \text{for } V < 75 \text{ cm (30 inches)}.$$

Basis for determining criterion-based weight limits

The University of Michigan 2D SSPP Program was used to determine biomechanically-based load weights that produce a disc compression of 350 kgs (3·4 kN) (i.e., the biomechanical criterion).

The University of Michigan Energy Expenditure Prediction Program was used to determine the physiologically-based load weights that produce energy expenditures equivalent to those displayed in table 3 for a lifting duration of 2–8 h. For example, where V is below 75 cm (tasks 1, 2, and 4), 3·1 kcal/min was used, where V is above 75 cm (task 3), 2·2 kcal/min was used.

[6] The 9·5 kcal/min baseline aerobic capacity value is equivalent to 90% of a 10·5 kcal/min baseline aerobic capacity for treadmill activity.

The psychophysically-based load weights for Tasks 1–3 were taken from Snook and Ciriello's (1991) female lifting database. The load weights are equivalent to the values that are acceptable to 75% of the female population for a 34 cm box width, 76 cm vertical displacement, and a lifting frequency of 4 lifts/min. For task 4, the load weight is taken from Ayoub *et al.* (1978) (table 8, p. 77, adjusted for 75% female acceptable).

D. Equations used to estimate energy expenditure from Garg (1976)

The following equations from Garg (1976) were used to estimate energy expenditure:

Stoop lift

$$E = 0{\cdot}0109\ BW + (0{\cdot}0012\ BW + 0{\cdot}0052\ L + 0{\cdot}0028\ S \times L)\ f \quad (1)$$

Squat lift

$$E = 0{\cdot}0109\ BW + (0{\cdot}0019\ BW + 0{\cdot}0081\ L + 0{\cdot}0023\ S \times L)\ f \quad (2)$$

Arm lift

$$E = 0{\cdot}0109\ BW + (0{\cdot}0002\ BW + 0{\cdot}0103\ L - 0{\cdot}0017\ S \times L)\ f \quad (3)$$

where:

E = energy expenditure (kcal/min)
BW = body weight (lbs)
L = weight of the load (lbs)
S = sex (female = 0, male = 1)
f = frequency of lifting (lifts/min)

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The NTIS Sales Desk (703) 487-4650 can provide pricing verification.