Quantifying Lifting Hazards

Alternatives beyond the NIOSH lifting equation

By Astra C. Townley, Dan M. Hair and David Strong

SOFT-TISSUE INJURIES or musculoskeletal disorders (MSDs) associated with manual lifting and awkward, repetitive use of the lower back account for approximately 28 percent of the occupational injuries and illnesses reported each year (BLS). Most SH&E professionals can readily identify key stressors that cause or aggravate MSDs (e.g., postures, force and repetition). Typically, qualitative methods such as checklists are employed during ergonomic assessments; on occasion, quantitative methods such as the NIOSH lifting equation are used.

While checklists help identify risk factors, they fail to provide a rigorous quantitative analysis that is repeatable and scientifically validated. However, the quantitative analytical approach required by the NIOSH equation is time-consuming and intrusive to the work process. This article provides an overview of four quantitative methods for characterizing lifting hazards. Using realistic case studies, the results achieved using three of these methods are compared to results achieved using the NIOSH equation in order to determine how these alternative methods compare to the NIOSH equation when applied to several typical work processes.

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Scope of the Problem

Although technology has advanced industrial production techniques, many jobs still require some manual materials handling and a small percentage require extensive manual materials handling. In 2000, lower back injuries related to manual materials handling accounted for 467,235 lost workday cases (BLS). Back strains and sprains account for 25.57 percent of the money spent for workers' compensation each year (Liberty Mutual). The combination of higher-than-average disability rates and rising medical costs have made MSDs the largest job-related injury and illness problem in the U.S. today. In addition to the direct costs of back strains and sprains, the indirect costs, such as reduced productivity or worker retraining costs, can be up to five times as great (OSHA). As a result, by quantifying lifting hazards in an efficient manner, the SH&E practitioner can better determine what controls should be implemented.

Revised NIOSH Lifting Equation

In 1981, NIOSH developed an equation to rate lifting tasks. A revised version was published in 1993 (Waters, et al) and is considered the gold standard by which lifting hazards are quantified. The equation is designed to help the user prevent or reduce the occurrence of lifting-related low back pain and injury among workers. The revised equation expanded the number of tasks that can be evaluated by providing methods for evaluating asymmetrical lifts; lifts of objects with less-than-optimal hand-container couplings; and guidelines for longer work durations and lifting frequencies. The equation considers six different factors in determining a recommended weight limit (RWL) for lifting and lowering of loads:

1) distance of the load from the body or horizontal origin (H);

2) location of the hands from floor level at the start of the lift or vertical origin (V);

3) vertical change between the origin and destination or distance (D);

4) lifts per minute or frequency (F);

5) angle of the load in relation to the torso or asymmetry (A);

6) quality of the grasps or coupling with the object (C);

Multipliers are assigned to each variable depending on the relative contribution of each to the overall risk of injury posed by the lift.

The process of measuring these variables can be intrusive for both the employee and the employer. The equation requires postures to be held so that accurate distance measurements can be obtained. For example, it is generally necessary to have the employee hold a pose in order to measure the vertical (V) and horizontal (H) origins of the lift. As a result, workflow can be slowed significantly.

Measurements taken are typically recorded on a worksheet. An RWL is then calculated by applying the multipliers to a load constant (LC) of 51 pounds. The LC and RWL are based on a specific set of task conditions and object weights that nearly all healthy workers can lift over a substantial time period (up to eight hours) without increasing their risk of developing back pain or injury.

The NIOSH equation makes several assumptions:

- Lifting and lowering tasks have the same level of risk for lower back injuries.
- The task is performed with two hands.
- Exposure duration is no more than eight hours.
- Workers are standing while performing tasks.
- Workers are physically fit.

It should be noted that several common lifting scenarios are not considered by the NIOSH model. These include lifting tasks that involve pushing, pulling or carrying; one-handed lifting; sitting, kneeling or lifting in a constrained or restricted work space; high-speed lifting; and unstable loads or containers of

liquid or incompletely filled bags. Although the NIOSH method integrates many of the biomechanical, physiological and psychological aspects of a lifting task, several less-intrusive and simpler methods for rating lifting tasks have been developed.

Alternative Methods

Biomechanical Model

Biomechanical methods consider the mechanics of muscular activity and the effect of different stresses on the body during work tasks (Chaffin and Andersson). These methods calculate acute and cumulative loads at the major body joints, particularly the lumbar spine region (Keyserling, et al). Biomechanical methods can be used to estimate the risk of injury associated with high-exertion tasks such as pushing, pulling, lifting, lowering, holding and carrying. Generally, the greater the forces exerted, the greater the degree of risk. For example, studies have shown that high force is associated with risk of injury in the lower back (Herrin, et al) as well as forearm/wrist (Silverstein, et al).

Biomechanical methods consider these factors:

•physical characteristics of the worker, including gender, height, weight;

•posture—positioning of the major body joints;

•load—magnitude and direction of force acting on each hand.

Studies suggest that there is an increased lumbar stress for lifting loads near the floor (Chaffin; Bean, et al). In addition, epidemiological studies indicate that lifting from near the floor is associated with a high percentage of low back injuries (Chaffin). Biomechanical studies also have indicated that increasing the horizontal distance of the load from the spine increases the compression forces on the disc (Chaffin).

For this overview, a 2D biomechanical model was used (Ergoweb). While this model is not suitable for all lifting tasks, it can be used to determine the compressive and shear forces exerted on the spine. It can also be used for extreme posture positions when one is lifting, lowering, pushing or pulling from a symmetrical standing posture. Each model also has limitations. For example, the 2D model does not consider the effects of repetitive lifting or the total duration of exposure.

Several assumptions must be made when using the 2D method. These include:

•minimal trunk rotation while performing the task;

•low task duration;

•low task frequency.

When using the 2D model, the analyst must first determine the most stressful position associated with the task. Typically, this occurs at the beginning or end of the movement or when the load is farthest from the lower back. Once this position is determined, a computer graphic model is reproduced. The compressive forces are then calculated based on the subject's gender, weight of load and position.

The following conclusions regarding the analyzed task can be made based on the results of the 2D computer model:

•No change is necessary when the total compressive force is less than 770 pounds.

•Administrative and/or engineering controls are recommended when the total compressive force is greater than 770 pounds but less than 1,430 pounds.

•Engineering controls are required when the total compressive force is greater than 1,430 pounds (Ergoweb).

Psychophysical Methods

Psychophysical methods consider the human response to work tasks. Snook and Ciriello pioneered much of the work in this area (Snook; Snook and Ciriello). The psychophysical approach is based on extensive scientific investigations of manual materials handling tasks to determine safe lifting weights. The methodology consisted of giving test subjects control over the weight being lifted in order to identify how long workers could work without straining or becoming unusually tired, weak or out of breath. These data were used to compile tables of maximum acceptable weight of load (MAWL) for male and female workers for lifts, lowers, pushes, pulls and carries. The tables, commonly referred to as the "Snook Tables," provide values of maximum acceptable weights. The data are further segmented into percentages representing 10, 25, 50, 75 and 90 percent of the theoretical industrial worker population.

To use these data in an evaluation, the population performing the task must be identified as must the percentage of that population the employer desires to accommodate. Other factors considered by the Snook Tables include:

•width of the box/object;

•location of lift;

•vertical distance of lift;

•frequency of lift.

To use these tables, one must know task type (lifting or lowering job); gender; physical characteristics (anthropometry) of the population performing the job; and lift/lower range (e.g., knuckle to floor). Once the values are determined, the numbers can be put into the appropriate table and the MAWL can be assessed. Snook concluded that a worker is three times more susceptible to low back injury if performing materials handling tasks that are comfortable for less than 75 percent of the female working population (Snook; Snook and Ciriello).

ACGIH Lifting Tables

American Conference of Governmental Industrial Hygienists (ACGIH) first proposed its lifting tables in 2002; they were adopted in 2003. ACGIH sets threshold limit values (TLVs) for lifting tasks based on biomechanical, psychophysical and epidemiological studies. ACGIH defines the lifting TLVs as "recommended workplace lifting conditions under which it is believed nearly all workers may be repeatedly exposed, day after day, without developing work-related low back and shoulder disorders associated with repetitive lifting tasks" (ACGIH).

The TLVs are compiled in three weight limit tables. (*Note: For the purposes of this article, weights* *were converted from kilograms to pounds.*) The tables are broken down by exposure duration and lifting frequency: Total lifting durations from two hours per day to more than 12 hours per day; and lifting frequencies ranging from 12 lifts per hour up to 360 lifts per hour. As with previous methods, the TLVs have limitations. Specifically, the lifting TLVs are designed for two-handed mono-lifting tasks performed within 30 degrees of the sagittal plane.

The first step is to select the appropriate table based on task frequency and duration. The second step is to identify the horizontal zone or the distance the object is from the spine. This aspect of the TLV method parallels the biomechanical model. Table 1 breaks down the horizontal distance into three ranges: close, intermediate and extended. The horizontal zone is determined by measuring the level distance from the midpoint between the inner ankle bones to the midpoint between the hands at the start of the lift.

The final step is to determine the vertical zone, which is based on the location of the hands at the start of the lift. Epidemiological studies have shown an increased risk for lifting below knuckle height (ACGIH). The junction of the horizontal and vertical zones determines the upper limits of an "acceptable" lift or TLV load.

Table 1

TLVs for Lifting Tasks

Two hours per day with 60 lifts per hour or more than two hours per day with 12 lifts per hour.

	HORIZONTAL ZONE *(mid-point of ankles)*		
VERTICAL ZONE	**Close** *<12 inches*	**Intermediate** *12 to 24 inches*	**Extended** *>24 to 31.5 inches*
High *(52 to 72 inches)* Reach limit, or 12 inches above shoulder to three inches below shoulder height	35 lbs.	15 lbs.	No known safe limit for repetitive lifting
Chest *(32 to 52 inches)* Knuckle height to below shoulder	70.5 lbs.	35 lbs.	19.8 lbs.
Low *(12 to 32 inches)* Middle shin to knuckle height	39.6 lbs.	31 lbs.	15 lbs.
Floor *(0 to 12 inches)* Floor to middle shin height	31 lbs.	No known safe limit for repetitive lifting	No known safe limit for repetitive lifting

A Study of the Methods

These four methods, summarized in Table 2, provide data that can be used to determine whether a lift is safe or hazardous. The availability of these alternatives leads to two questions: 1) Is there significant variability between consultants using the same tool? 2) Is there significant variability between tools applied to the same task?

To answer these questions, six consultants with above-average knowledge of ergonomics were asked to analyze several jobs. All consultants involved had received more than 60 contact hours of training from Ergoweb and had applied the tools consistently over a two-year period. Each consultant was asked to select a job that met the following criteria:

- mono (single) task lifting job;
- palletizing/depalletizing task (bagging/boxing);
- performed at least four hours a day;
- object weight of 25 to 80 pounds.

Each consultant provided the other participants in the study with a videotape and digital photographs of his/her self-selected job. On-site measurements of all jobs were compiled and provided to participating consultants on a worksheet (Figure 1).

Table 2

Comparison of the Four Methods

Method	Strengths	Limitations	Average Costs (Time)
NIOSH	•Encompasses all methods •Force, torque, gender, frequency, duration	•Not protective of all workers •Experience in use	Experienced user of tool—75 minutes per task evaluating
2D Biomechanical	•Tasks not requiring repetition or extended duration •Compressive force •Limited computations—observational	•No account for repetition and duration •Individual determination of most stressful position	With computer modeling 25 minutes
Snook Tables	•Determines maximum acceptable weight limits •Limited computations—observational •Gender (anthropometrics), distance, task type, frequency	•Determining percentage group to perform •No account for body posture •Frequency limitations	45 minutes per task
ACGIH Lifting TLVs	•Determine safe limits •Posture, frequency, force •Minimal measurements	•Mono-lifting tasks •Frequency limitations	50 minutes

Each consultant applied the four selected tools (NIOSH, Snook Tables, 2D model and ACGIH) to his/her self-selected job as well as to those selected by the other consultants (Figure 2).

The six jobs selected were: 1) palletizing job that entailed lifting 75-pound bags of flour from the fill machine and placing them on a pallet; 2) palletizing job that entailed taking 44-pound boxes off a con-

Figure 1

Lifting Evaluation Worksheet

LIFTING EVALUATION WORKSHEET

PRIMARY INFORMATION

Name of Consultant:		Date	
Name of Company		Contact:	

TASK INFORMATION

Job Title:	
Brief Description:	

TOOLS

Tools Used:	Weights:	Location:
Tools Used:	Weights:	Location:
Tools Used:	Weights:	Location:
Tools Used:	Weights:	Location:

MEASUREMENTS

ITEM	RESULTS	
Gender of Most employees in area:	Male	Female
Percentile to be Used (industrial population)		
Width of Item (in inches)		
Weight of Load		
Starting Load Position (inches away from body)		
Starting Load Height (inches above/below the waist)		

Figure 2

Consultant Worksheet

	JOB #1	JOB #2	JOB #3
Task Description: Palletizing/ Depalletizing	*Palletizing*	*Palletizing*	*Palletizing*
Weight of Load	*75 lbs.*	*44 lbs. (19.95 kg)*	*46 lbs.*
Gender	*Male*	*Male*	*Female*
NIOSH Factors			
Load Constant	*51 lbs.*	*51 lbs.*	*51 lbs.*
Horizontal Location	*O=14"/D=14"*	*O=19"/D=23"*	*O=9"/D=12"*
Vertical Distance	*O=42"/D=10"*	*O=24"/D=13"*	*O=22"/D=9"*
RESULT			
2D Biomechanical			
Industrial Profile	*50%*	*50%*	*50%*
Weight of Individual	*217 lbs.*	*166 lbs.*	*130 lbs.*
Height (in.)	*74"*	*70"*	*62"*
Task Description	*Lift/lower using both hands*	*Lift/lower using both hands*	*Lift/lower using both hands*
RESULT			
Snook Tables			
% Population Job	*75%*	*75%*	*75%*
Object Width	*24"*	*19.5"*	*15"*
Vertical Distance of Lift	*30"*	*11"*	*13"*
RESULT			
ACGIH TLVs			
Hours per Day	*>2 hours per day*	*>2 hours per day*	*>2 hours per day*
# Lifts/hour			
Table Used			
RESULT			

veyor and stacking them onto a pallet for shipping; 3) palletizing job that involved lifting 44-pound boxes off a conveyor onto a pallet; 4) depalletizing job that involved lifting wide 37-pound boxes off a pallet and loading into a truck; 5) depalletizing job that entailed lifting 10-pound stacks of paper off a pallet and placing them into a feeder; and 6) palletizing job that involved taking 50-pound flour sacks off a conveyor and placing them onto a pallet.

Each job presented unique mixes of risk factors to ensure that a reasonable range of exposures was tested. Results from each participant were compiled on a spreadsheet for final review and data compilation. The data for each lifting task were sorted into three risk levels—green, yellow and red (Ergoweb). Green represented tasks within safe lifting limits that required no changes. Yellow jobs were those that might require administrative or engineering controls. Red jobs had tasks that required engineering controls.

Results

Variability Among Consultants

Variability was determined by looking at the raw data and assigning risk level color zones for each evaluation method. For example, using NIOSH, a lifting index greater than 2.0 would result in a task being identified as red zone. If all consultants' data for a specific job fell within this zone, it was deemed that there was no variability. Variability increased as the consensus between consultants diverged. Ergoweb's website was used to determine color zones for each of the evaluation methods.

Using this variability criteria, it was found that the smallest amount of variation between consultants occurred when using the NIOSH lifting equation. In Job 1, where the weight of the load exceeded 51 pounds (RWL for NIOSH), the variation

Table 3

Evaluation Results: Variability Among Consultants

Results from each participant were compiled and data for each task were sorted into three risk levels—green, yellow and red.

Job	Risk Level	NIOSH	NIOSH Raw	2D Biomechanical Model	2D Raw	Snook	Snook Raw	ACGIH	ACGIH Raw
Job 1	Green	0%	0	0	0	0%	0	0%	0
	Yellow	0%	0	0	0	0%	0	0%	0
	Red	100%	6	100%	6	100%	6	100%	6
Job 2	Green	0%	0	17%	1	17%	1	0%	0
	Yellow	0%	0	83%	5	67%	4	17%	1
	Red	100%	6	0%	0	17%	1	83%	5
Job 3	Green	0%	0	83%	5	0%	0	0%	0
	Yellow	100%	6	17%	1	17%	1	17%	1
	Red	0%	0	0%	0	83%	5	83%	5
Job 4	Green	0%	0	33%	2	50%	3	0%	0
	Yellow	0%	0	67%	4	50%	3	0%	0
	Red	100%	6	0%	0	0%	0	100%	6
Job 5	Green	100%	6	100%	6	100%	6	17%	1
	Yellow	0%	0	0%	0	0%	0	33%	2
	Red	0%	0	0%	0	0%	0	67%	4
Job 6	Green	0%	0	0%	0	0%	0	0%	0
	Yellow	0%	0	100%	6	100%	6	17%	1
	Red	100%	6	0%	0	0%	0	83%	5

between consultants for all methods was low. As Table 3 shows, for this job, all consultants determined—with each method—that the lift was in the red zone. However, in the other jobs, conclusions were not always consistent despite the fact that all participants received the same raw data.

The variability between consultants is partly because the biomechanical model, Snook Tables and ACGIH TLV tables allow for some subjectivity. For example, to use the biomechanical model, one must determine the most hazardous posture involved in conducting the task. Each evaluator could select a different posture. In addition, a replica of the posture must be drawn on paper and the angles determined. While weight, stature and object weight are measurable variables, redrawing the posture can lead to variations in the angles, which, in turn, influence the results of the compressive force.

To illustrate this point, consider a case where the torso position is determined to be at a 22-degree angle with arms extended to a 78-degree angle. In this example, the total compressive force is calculated to be greater than 1,430 pounds requiring engineering controls. However, by keeping the angle of the torso at 22 degrees yet slightly bending the arms to a 34-degree angle and changing the legs, the calculated force is reduced to less than 770 pounds and the task becomes significantly safer. Clearly, the 2D model requires substantial practitioner skill in determining body postures and angles.

Less variability was expected in results with the Snook Tables, but this was not necessarily the case. These tables consider gender, range of the lift, object width, vertical distance of the lift and the frequency. Variations in the results usually were found in the calculation of lifting frequency and determination of the lift lower range. Differences in the lift lower range appeared to have the greatest impact on the task's hazard rating.

Of the four models, ACGIH's tables were the easiest to use, but once again the greatest factor affecting the results was determining the vertical zone of the lift. In using the ACGIH model, once the frequency was determined and the appropriate table selected, variations among participants were found in the selection of the appropriate vertical zone.

Variability between consultants increased when comparing results using the 2D model and Snook Tables. ACGIH's TLV method showed some variability between practitioners but less dramatically than the other methods.

Variability Between Methods

To examine variability between the different methods, a comparison table was created (Figure 3). The bold number in the middle of each cell denotes the percentage of agreement between the two methods (column vs. row).

Review of the four methods reveals that NIOSH and ACGIH yielded the highest agreement. More than 61 percent of the time, participants reached the same conclusions using these two methods. The rationale behind this is that both methods combine the biomechanical, psychosocial and epidemiological aspects in determining whether a lifting task is hazardous; consequently, the results from these two methods tend to correlate better.

At the other extreme, the biomechanical model in most instances did not result in a more-protective result. This is likely because the 2D model looks at only one component of the task—compressive/shear forces exerted on the back at one moment in time. This model does not take into account task frequency or duration, as in the other three models. The Snook Tables had at least a 36-percent correlation with the NIOSH and ACGIH methods, but in this study, these tables only provided a more-protective risk rating when compared to the 2D model.

Figure 3

Variability Between Methods Evaluated

	NIOSH	2D Biomechanical	Snook	ACGIH
NIOSH		0 / **19.4** / 80.6	13.8 / **38.8** / 47.4	27.7 / **61.1** / 11.2
2D Biomechanical	80.6 / **19.4** / 0		38.8 / **47.7** / 13.5	94.4 / **5.6** / 0
Snook	47.4 / **38.8** / 13.8	13.5 / **47.7** / 38.8		55.5 / **36.1** / 8.4
ACGIH	11.2 / **61.1** / 27.7	0 / **5.6** / 94.4	0 / **36.1** / 63.9	

Key

% of column more protective

% agreement

% of row more protective

Conclusion

The development of quantifiable ergonomic risk assessment tools has given SH&E professionals a more credible way to address injury risk factors. Each tool is founded on research and interdisciplinary professional collaboration. All of the tools examined produce results that can be helpful in developing injury prevention strategies. Each tool has built-in assumptions and in some cases, limitations that must be considered when selecting a tool, as these factors can impact the level of protection provided.

The NIOSH lifting equation produced unanimous outcomes across the six cases studied. This tool provides a high level of protection to the worker and captures all primary ergonomic risk factors. It also encompasses both the biomechanical and psychophysical approaches of the other models. However, it is more complex and its proper application requires worker cooperation and the ability to suspend work for some time. In the authors' experience, in an industrial setting, particularly with smaller businesses, this can restrict its acceptance and usability.

The ACGIH method produced outcomes closest to those obtained with the NIOSH equation and it is less obtrusive and easy to use. This tool draws sharp lines when it comes to lifting from the floor or above the shoulder, which may limit its usefulness in some settings involving low-load/low-frequency tasks. Also, it does not address asymmetric lifts, coupling quality or individual worker anthropometric differences.

The Snook Tables and 2D biomechanical model are both robust tools, yet they allow for some subjective differences. Both are relatively easy to use and have limited impact on work; in addition, as these data show, both were usually in line with results generated using the NIOSH equation. The 2D tool has the additional (and not inconsequential) advantage of demonstrating—graphically—the effect of changes in lifting variables.

It is not easy to determine which tool is most appropriate. The results of this study show that several tools with varying degrees of complexity can be used to identify hazardous tasks. Where actual injury patterns or multi-worker exposure exists, best practice demands evaluation of risks through a combination of tools selected for their sensitivity to individual risk factors. In other cases, the application of any one of these tools alone may suffice. ■

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