# Variable Lifting Index (VLI): A New Method for Evaluating Variable Lifting Tasks

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**Objective:** We seek to develop a new approach for analyzing the physical demands of highly variable lifting tasks through an adaptation of the Revised NIOSH (National Institute for Occupational Safety and Health) Lifting Equation (RNLE) into a Variable Lifting Index (VLI).

**Background:** There are many jobs that contain individual lifts that vary from lift to lift due to the task requirements. The NIOSH Lifting Equation is not suitable in its present form to analyze variable lifting tasks.

**Method:** In extending the prior work on the VLI, two procedures are presented to allow users to analyze variable lifting tasks. One approach involves the sampling of lifting tasks performed by a worker over a shift and the calculation of the Frequency Independent Lift Index (FILI) for each sampled lift and the aggregation of the FILI values into six categories. The Composite Lift Index (CLI) equation is used with lifting index (LI) category frequency data to calculate the VLI. The second approach employs a detailed systematic collection of lifting task data from production and/or organizational sources. The data are organized into simplified task parameter categories and further aggregated into six FILI categories, which also use the CLI equation to calculate the VLI.

**Results:** The two procedures will allow practitioners to systematically employ the VLI method to a variety of work situations where highly variable lifting tasks are performed.

**Conclusions:** The scientific basis for the VLI procedure is similar to that for the CLI originally presented by NIOSH; however, the VLI method remains to be validated.

**Application:** The VLI method allows an analyst to assess highly variable manual lifting jobs in which the task characteristics vary from lift to lift during a shift.

**Keywords:** biomechanics, physical ergonomics, job analysis, manual materials handling, risk assessment

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## INTRODUCTION

The variability of task characteristics, such as the weight of the load being lifted and the geometry of the lift (e.g., horizontal reach, vertical height, etc.), between lifts in manual lifting jobs within industry makes it difficult to assess their overall physical demand or risk of musculoskeletal disorder. Generally, manual lifting jobs in industry can be categorized according to the variability of the task characteristics between lifts within the job.

As described by Waters, Occhipinti, Colombini, Alvarez, and Hernandez (2009), the four categories of lifting are as follows:

1. Single-task manual lifting involves task characteristics that do not vary significantly from lift to lift or only one lift is of interest. Examples of this category of task may include performing a single heavy lift per day or the lifting of the same part repetitively on assembly lines.
2. Multiple-task manual lifting involves jobs that consist of a small set of unique repetitive lifting tasks (less than 10) that may be performed concurrently during a prescribed period of time. Examples of this type of task would include many palletizing jobs.
3. Sequential manual lifting involves tasks in which a worker rotates between different workstations during a shift or other period of time. At each workstation, the worker has to perform a different series of specified lifting tasks and each rotation position in the job may have its own set of unique single- or multitask lifting activities.
4. Variable-task manual lifting involves jobs where all of the lifts are highly variable. These types of jobs are the most difficult to analyze from an ergonomics perspective. Examples of this category of task may include manual lifting in warehouse operations, baggage handling, and small lot

material delivery in assembly line manufacturing operations.

Waters et al. (2009) first described a new method, the Variable Lifting Index (VLI), to assess the physical demands of jobs with variable manual lifting tasks. The purpose of the present paper is to expand on the background and application of the VLI and to provide two detailed approaches to the use of the VLI for industrial practitioners.

Historically, jobs with variable task characteristics have been difficult to evaluate, and the need for such an approach has been documented in previous studies. For example, in a study of grocery order selectors (also called “pickers”) in a dry goods warehouse, Waters, Baron, and Putz-Anderson (1998) attempted to assess the physical demands for selectors due to manual lifting of boxes of groceries. The order selector job involved repetitive lifting of cases of grocery items from supply pallets to an electrically driven pallet jack that moves along the aisles of the warehouse. To assess the physical demands of the order selector job, a variety of ergonomic assessment tools were used to evaluate the physical demands of the lifting job and a questionnaire was administered to selectors to determine their perceptions of physical workload and symptoms of musculoskeletal disorders. The ergonomic assessment tools included the single task recommended weight limit (RWL) and lifting index (LI) equations from the Revised NIOSH (National Institute for Occupational Safety and Health) Lifting Equation (RNLE; Waters, Putz-Anderson, & Garg, 1994), the University of Michigan 3D Static Strength Prediction Program (Chaffin & Andersson, 1991), an Oxylog portable oxygen consumption meter (O2), a portable heart rate monitor, a Lumbar Motion Monitor, The Ohio State University Risk Assessment Model (Marras, Fathallah, Miller, Davis, & Mirka, 1992), and the Liberty Mutual psychophysical method for assessing manual lifting (Snook & Ciriello, 1991).

Based on the results obtained from the warehouse studies, it was apparent that all six of the ergonomic methods used in that study indicated that the job of grocery selector has a high level of risk for low back pain, but there were differences in the predicted level of physical demand and risk of low back pain derived from the various methods. The authors stated that variability in task characteristics between lifts associated with the grocery selector job presented a problem for nearly all of the assessment methods applied. When the conditions vary significantly between exertions, there is little capability to accurately evaluate these variations. The authors also suggested that more research is needed to develop sampling methods that allow integration of variable physical loading between tasks and across a work shift.

Another example of manual handling jobs with highly variable task characteristics is provided by the “just-in-time” or material pull system where small lots of material are in large part manually delivered to production lines in production line manufacturing systems. The pull systems were commonly called “Kanban” from the Japanese term meaning “label.” The systems require the delivery of small lots of material in totes or containers to production lines and may involve great variety in the weights, sizes, and frequency of items delivered to production lines. The ergonomics issues with such systems and the challenges in the analysis of industrial small lot material delivery jobs have been described (Fox & Peacock, 1995). Two of the authors of the present paper, Waters and Fox, contributed to an industry group effort at modifying the NIOSH 1991 Lift Equation to address such variable tasks (Automotive Industry Action Group, 2007).

Mirka et al. developed the Continuous Assessment of Biomechanical Stress (CABS) method to assess variable manual lifting jobs (Mirka, Kelaher, Todd Nay, & Lawrence, 2000). The approach allowed for assessing jobs with highly variable physical demands across a shift. The CABS method was designed to allow the accumulation of loading across variable lifts in the construction industry and was used to assess jobs with variable manual materials handling (MMH) requirements in the crab fishing industry (Mirka, Shin, Kucera, & Loomis, 2005).

Others have developed cumulative load models based on assessment of biomechanical loads for individual lifts that were then added together to obtain a measure of overall load as a function of time (Kumar, 1990; Norman et al., 1998; Seidler et al., 2001; Stuebbe, Genaidy, Karwowski, Young, & Alhemood, 2002).

In this paper, an approach using the RNLE to assess the cumulative demands is explored. The RNLE is likely more familiar and assessable to a greater number of potential users.

## VLI CONCEPT

The basic VLI method for assessing variable lifting jobs was described in a study by Waters et al. (2009). The concept for the VLI is analogous to that of the Composite Lift Index (CLI) (Waters et al., 1994), although Frequency Independent Lift Index (FILI) categories are defined into which the individual lifting tasks are aggregated. These FILI categories are then treated as if they were individual lifts in the CLI equation with the frequency multiplier (FM) for each category determined from the average frequency of lifts within each of the individual FILI categories. Based on the FILI and FM values for each category, the VLI for the job (frequency-weighted estimate of the overall physical demand of the job itself) is calculated. Although as many as nine FILI categories can be used, we choose to use six categories in the current model, as numerically it seemed that six categories cover a range of FILI more efficiently than a lesser or greater number of categories.

## TWO APPROACHES FOR OBTAINING DATA FOR THE VLI

The two different approaches for obtaining the data needed to apply the VLI procedure for a highly variable manual lifting job were first suggested by Waters et al. (2009) and Colombini, Occhipinti, Alvarez, Hernandez, and Waters (2009). Those approaches will be explained in more detail in this paper with detailed examples provided. The first approach is referred to as the "sampling approach" and requires that task data be obtained from a subset of the lifts that occur during a shift. The sufficient number of samples required will differ, depending upon the range of variability of the lifting tasks performed during the day. The second approach is referred to as the "systematic organizational analysis approach" and is based on a comprehensive assessment of the lifting tasks in order to analytically determine the overall duration of the variable lifting task in the shift. Data collected or estimated include the number of objects of different weight lifted during this time, the number of workers involved, the overall frequency of lifts, the partial frequency of lifts for each weight (or group of similar weights), and finally, by direct observation of workplaces and using a probabilistic approach, the approximate frequencies of individual lifts. The second approach utilizes production or sales data (for durations, weights, and overall and partial frequencies) or probability distribution data (for geometries and subpartial frequencies). This approach may require some simplifications or assumptions about the weights lifted and the geometries of the lifts during a shift to be used in the RNLE (Waters, Putz-Anderson, Garg, & Fine, 1993; Waters et al., 1994), as noted below.

Regardless of the approach used, it is necessary to determine the overall average lifting frequency across the work shift, relative work/rest patterns, weights of loads lifted, and measured or predicted geometries of lifts. The overall frequency of lifting likely will vary from day to day, but a single estimate is needed in order to arrive at the partial frequencies for each category of FILI values. The relative pattern of work/rest is determined as explained in the *Applications Manual for the Revised NIOSH Lifting Equation* (Waters et al., 1994). It should be noted here that the required ratio of work time to rest time for the short duration category was changed from 1.2 to 1.0 in 2006 (Waters, 2006). The steps in the VLI analysis will differ, depending upon whether the "sampling approach" or the "systematic organizational analysis approach" is used. The steps for the two approaches are discussed below.

### Approach Based on Task Sampling

The recommended steps are as follows (Waters et al., 2009):

1. Collect task data needed to compute the FILI and single task lifting index (STLI) for each lift from a subset of lifts performed by the worker during a shift. The sample should be representative of the distribution of task characteristics and relative frequencies of tasks.
2. Define the range of FILI values for all of the sampled lifts.

3. Divide the range of FILI values into six categories of equal magnitude.
4. Assign each sampled lift into the appropriate FILI category and determine the average frequency of lifts in each of the categories.
5. Calculate the VLI using the CLI equation, but use the frequency data for each LI category to calculate the appropriate FM values for the calculation.

The VLI is computed as follows:

- The LI categories are renumbered in order of decreasing physical stress, beginning with the task category with the greatest STLI, down to the task category with the smallest STLI. The STLI is defined as the LI value for each task or task category, independent of the other tasks or categories.
- The VLI for the job is then computed according to the following formula (same formula as used for the CLI as in Waters et al., 1994):

$$\mathrm{VLI} = \mathrm{STLI}_1 + \sum \Delta \mathrm{LI}, \qquad (1)$$

where:

$$\sum \Delta LI = (FILI_2 X(\frac{1}{FM_{1,2}} - \frac{1}{FM_1}))$$
$$+(FILI_3 X(\frac{1}{FM_{1,2,3}} - \frac{1}{FM_{1,2}}))$$
$$+(FILI_4 X(\frac{1}{FM_{1,2,3,4}} - \frac{1}{FM_{1,2,3}}))$$
$$\ldots$$
$$+(FILI_n X(\frac{1}{FM_{1,2,3,4,\ldots,n}} - \frac{1}{FM_{1,2,3,\ldots,(n-1)}}))$$

Note, that:

(a) the numbers in the subscripts refer to the new LI task category numbers, and
(b) the FM values are determined from the frequency table published in the *Applications Manual for the Revised NIOSH Lifting Equation* (Waters et al., 1994).

The $\mathrm{STLI}_1$ is the single highest STLI value for any of the sampled lifts. The appropriate FM values are based on the sum of the frequencies for the task categories listed in the subscripts.

*Example of sampling approach*. In order to demonstrate how the VLI method can be applied to a variable lifting job, a simple example of the sampling approach is provided to show how the VLI equation should be applied. For this example, we sampled 25 lifts from a worker over a shift. The RNLE data we obtained for the 25 lifts are listed in Table 1. Remember, these 25 lifts are a representative subset of the total lifts performed by the worker during the shift. Table 1 displays the object weight, horizontal location, vertical height, vertical displacement, asymmetry angle, coupling, and calculated FILI for each of the 25 sampled lifts. For simplicity, it is assumed that significant control is not required for any of the lifts and the overall lifting frequency across the shift is three lifts per minute. Based on the measured data, it can be seen that the largest FILI value sampled for any individual lift was 2.5 and the smallest FILI value was 0.3.

According to the VLI procedure, the range of FILI categories should be evaluated and a set of FILI categories should be chosen. This is accomplished by dividing the overall range of FILI values into a fixed number of equal size categories. The choice of FILI categories is somewhat arbitrary, but we suggest choosing six categories.

For this example, six FILI categories were chosen. In order to determine the spans for the six categories, the difference between the maximum FILI and the minimum FILI is divided by the number of categories (six). Therefore, the span for this example is 2.5–0.3, or 2.2. Thus, each category would span a range of 2.2/6 or 0.366 units on the LI scale, resulting in six categories defined as 0.3–0.67, 0.68–1.0, 1.1–1.4, 1.5–1.8, 1.9–2.1, and 2.2–2.5. Each lift is then assigned to one of the six categories based on the magnitude of the FILI values. The categorical assignments are shown in Table 1.

The intermediate calculations for the VLI example are shown in Table 2. The representative FILI value for the category containing the single task with the largest FILI is assigned that maximum value (a value of 2.5 in Table 2). The representative value within each of the other categories was computed by averaging the FILI values for all the sampled lifts in each of the respective categories. The number of lifts

**TABLE 1:** Task Data for VLI Hypothetical Example

| Sample No. | Wt | H | V | D | A | C | RWL | FILI | STLI | LI Cat |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 22 | 22 | 5 | 25 | 15 | G | 13.8 | 1.6 | 1.9 | 4 |
| 2 | 15 | 17 | 22 | 8 | 30 | P | 18.8 | 0.8 | 0.9 | 2 |
| 3 | 31 | 13 | 5 | 25 | 0 | P | 19.4 | 1.6 | 1.9 | 4 |
| 4 | 25 | 22 | 43 | 13 | 15 | F | 16.7 | 1.5 | 1.8 | 4 |
| 5 | 16 | 17 | 68 | 38 | 45 | G | 13.3 | 1.2 | 1.4 | 3 |
| 6 | 8 | 13 | 22 | 8 | 30 | F | 26.7 | 0.3 | 0.4 | 1 |
| 7 | 18 | 21 | 5 | 25 | 15 | P | 12.9 | 1.4 | 1.6 | 3 |
| 8 | 31 | 15 | 43 | 13 | 0 | G | 23.9 | 1.3 | 1.5 | 3 |
| 9 | 22 | 18 | 22 | 8 | 15 | F | 20.0 | 1.1 | 1.3 | 3 |
| 10 | 16 | 21 | 5 | 25 | 45 | G | 12.3 | 1.3 | 1.5 | 3 |
| 11 | 31 | 12 | 68 | 38 | 30 | P | 18.2 | 1.7 | 1.9 | 4 |
| 12 | 8 | 18 | 5 | 25 | 0 | P | 16.0 | 0.5 | 0.6 | 1 |
| 13 | 25 | 22 | 22 | 8 | 15 | G | 17.9 | 1.4 | 1.6 | 3 |
| 14 | 18 | 10 | 22 | 8 | 30 | F | 36.0 | 0.5 | 0.6 | 1 |
| 15 | 22 | 24 | 68 | 38 | 45 | P | 8.8 | 2.5 | 2.9 | 6 |
| 16 | 8 | 17 | 43 | 13 | 0 | G | 20.0 | 0.4 | 0.5 | 1 |
| 17 | 16 | 10 | 68 | 38 | 15 | F | 26.7 | 0.6 | 0.7 | 1 |
| 18 | 25 | 24 | 43 | 13 | 0 | P | 13.9 | 1.8 | 2.1 | 4 |
| 19 | 8 | 12 | 5 | 25 | 15 | F | 26.7 | 0.3 | 0.4 | 1 |
| 20 | 12 | 18 | 68 | 38 | 30 | F | 13.3 | 0.9 | 1.1 | 2 |
| 21 | 19 | 15 | 5 | 25 | 0 | G | 19.0 | 1.0 | 1.2 | 2 |
| 22 | 31 | 13 | 22 | 8 | 45 | P | 23.9 | 1.3 | 1.5 | 3 |
| 23 | 22 | 21 | 68 | 38 | 30 | P | 11.0 | 2.0 | 2.4 | 5 |
| 24 | 16 | 13 | 43 | 13 | 0 | G | 26.7 | 0.6 | 0.7 | 1 |
| 25 | 8 | 15 | 22 | 8 | 15 | F | 26.7 | 0.3 | 0.4 | 1 |

*Note*. A = asymmetry angle; C = coupling quality; D = vertical displacement (in.); FILI = frequency independent lift index; H = horizontal distance (in.); LI Cat = lifting index category for VLI calculation; RWL = recommended weight limit (lb); STLI = single task lifting index; V = vertical height (in.); VLI = variable lifting index; Wt = object weight (lb).

assigned to each category and the percentage of tasks falling into each of the six cells is also shown in Table 2. The lifting frequency for each category is determined by multiplying the percentage of lifts in each category times the overall frequency (3/min), as shown in Table 2. As with the SLI approach, the VLI approach works best if the job is performed for a full 8-hour shift (Waters, Lu, & Occhipinti, 2007). Based on the data shown in Table 1, intermediate calculations for the VLI example can be computed as shown in Table 2.

For this example, we assumed that the overall frequency of lifting across an 8-hour shift is 3/min.

Based on the data presented, the VLI for this job can be calculated, as follows:

$$VLI = STLI_1 + \sum \Delta LI$$

$$STLI_1 = 2.90$$

$$\Delta FILI_2 = 2.0\ \left(\left(1/.84\right) - \left(1/.85\right)\right) = 0.01$$

$$\Delta FILI_3 = 1.64\ \left(\left(1/.77\right) - \left(1/.84\right)\right) = 0.18$$

$$\Delta FILI_4 = 1.29\ \left(\left(1/.68\right) - \left(1/.77\right)\right) = 0.22$$

$$\Delta FILI_5 = 0.90\ \left(\left(1/.65\right) - \left(1/.68\right)\right) = 0.06$$

$$\Delta FILI_6 = 0.44\ \left(\left(1/.55\right) - \left(1/.65\right)\right) = 0.12$$

**TABLE 2:** Intermediate Calculations for VLI Example in Table 1

| | LI Categories | | | | | |
|---|---|---|---|---|---|---|
| Data Category | 0.3–0.67 | 0.68–1.0 | 1.1–1.4 | 1.5–1. 8 | 1.9–2.1 | 2.2–2.5 |
| Representative FILI within category | 0.44 | 0.90 | 1.29 | 1.64 | 2.0 | 2.5 |
| Number of tasks in each category | 8 | 3 | 7 | 5 | 1 | 1 |
| Percentage of tasks | 32% | 12% | 28% | 20% | 4% | 4% |
| Frequency (lifts/min) | 0.96 | 0.36 | 0.84 | 0.60 | 0.12 | 0.12 |
| Reordered by decreasing FILI value (highest = 1) | 6 | 5 | 4 | 3 | 2 | 1 |

*Note.* FILI = frequency independent lift index; LI = lifting index; VLI = variable lifting index.

$$\text{VLI} = \text{STLI}_1 + \Delta\text{FILI}_2 + \Delta\text{FILI}_3 + \Delta\text{FILI}_4 + \Delta\text{FILI}_5 + \Delta\text{FILI}_6$$

$$\text{VLI} = 2.90 + 0.01 + 0.18 + 0.22 + 0.06 + 0.12 = 3.49.$$

In order to demonstrate how variations in lifting frequency within the job affects the overall VLI calculation, we can examine a job with the same series of lifts as previously shown but with different task frequencies. Table 3 shows data for the same job as shown in Table 2, but with different frequencies for tasks within the job. As can be seen in Table 3, the number of tasks within each LI category is different, because the frequencies of the tasks are different within each category.

The VLI calculation for this example, with different frequencies, is shown below. For this alternate example, we assumed that the representative FILI within each category remained the same as before:

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

$$\Delta\text{FILI}_2 = 2.0\ \left(\left(1/.74\right) - \left(1/.82\right)\right) = 0.26$$

$$\Delta\text{FILI}_3 = 1.64\ \left(\left(1/.68\right) - \left(1/.74\right)\right) = 0.20$$

$$\Delta\text{FILI}_4 = 1.29\ \left(\left(1/.61\right) - \left(1/.68\right)\right) = 0.22$$

$$\Delta\text{FILI}_5 = 0.90\ \left(\left(1/.58\right) - \left(1/.61\right)\right) = 0.08$$

$$\Delta\text{FILI}_6 = 0.44\ \left(\left(1/.55\right) - \left(1/.58\right)\right) = 0.04$$

$$\text{VLI} = \text{STLI}_1 + \Delta\text{FILI}_2 + \Delta\text{FILI}_3 + \Delta\text{FILI}_4 + \Delta\text{FILI}_5 + \Delta\text{FILI}_6$$

$$\text{VLI} = 2.90 + 0.26 + 0.20 + 0.22 + 0.08 + 0.04 = 3.70.$$

As can be seen from this example, as the percentage of tasks with larger FILI values increases, the VLI value of the overall job also increases. For this example, the increased frequencies of tasks with higher FILI values increased the VLI of the overall job from 3.49 to 3.7. Similarly, if the percentage of tasks with lower FILI values increases, the VLI for the overall job would have been lower than before.

### Approach Based on Systematic Organizational Analysis

The sampling approach, although useful in many practical situations, does present some limitations in that the task variables need to be sufficiently constant during the sampling period and limited in order to keep the representative tasks to no more than 30. As mentioned previously, the Systematic Organizational Analysis approach is based on a systematic assessment of the job using job and task data derived from methods other than sampling methods, such as production or sales data (existing data for durations, weights, and overall and partial frequencies) or probability distribution data (for geometries and subpartial frequencies).

This assessment approach requires knowledge of the total duration of the lifting tasks during the

**TABLE 3:** Hypothetical Data for Alternate VLI Example in Table 1

| | LI Categories | | | | | |
|---|---|---|---|---|---|---|
| Data Category | 0.3–0.67 | 0.68–1.0 | 1.1–1.4 | 1.5–1. 8 | 1.9–2.1 | 2.2–2.5 |
| Representative FILI within category | 0.44 | 0.90 | 1.29 | 1.64 | 2.0 | 2.5 |
| Number of tasks in each category | 2 | 3 | 5 | 6 | 7 | 2 |
| Percentage of tasks | 8% | 12% | 20% | 24% | 28% | 8% |
| Frequency (lifts/min) | 0.24 | 0.36 | 0.60 | 0.72 | 0.84 | 0.24 |
| Reordered by decreasing FILI value (highest = 1) | 6 | 5 | 4 | 3 | 2 | 1 |

*Note.* FILI = frequency independent lift index; LI = lifting index; VLI = variable lifting index.

work shift, number and weight of the different objects lifted, number of workers who do the lifting, total and partial frequency of lifts, and the work/rest pattern for the job. All of the lifts performed by a worker are categorized into a maximum number of 30 FILI values that are representative of the range of FILI values that would be observed in the entire sample. The frequencies of each of the FILI values are then determined from production data (considering weight groups) or from probability estimates of the distributions (considering observed geometries). In order to use this approach, several simplifications may be necessary, especially when many different objects are lifted with widely varying weights and geometries. This is because, without simplifications, the number of individual FILI values would be very large (hundreds and, sometimes, thousands) and practically impossible to manage. One approach is to set up a simplified series of weight and geometry values from which a limited set of FILI values can be derived. The following general procedure for simplifying a large number of lifting tasks was suggested by Colombini et al. (Colombini et al., 2009; Colombini, Occhipinti, Alvarez-Casado, & Waters, 2012):

1. Compress the potential individual lifting tasks in the job into a structure that considers up to a maximum of 30 subtasks (and corresponding FILI and STLI) for different loads (weight categories, WTCs) and geometries using the following approach:

- Aggregate up to 5 objects (weights) categories.
- Classification of vertical location (vertical multiplier, VM) in only two categories (good/bad).
- Classification of horizontal location (horizontal multiplier, HM) in up to three categories (near, mid, far).
- Presence/absence of “asymmetry” (asymmetric multiplier, AM) assessed for each WTC (by threshold value for all the lifts in the category).
- Daily duration of lifting classified as in the *Applications Manual for the Revised NIOSH Lifting Equation* (Waters et al., 1994).
- Frequencies of lifts specifically determined or estimated for each subtask and FILI, with FMs determined as in the *Applications Manual for the Revised NIOSH Lifting Equation* (Waters et al., 1994).
- Vertical displacement (vertical distance multiplier, DM) and coupling (coupling multiplier, CM) are both considered as a constant.

At the end it will be possible to compute individual FILI and STLI for up to 30 subtasks.

2. Once the selected FILI values are derived, the entire set of FILI values are assigned into a fixed number of FILI categories. We suggest six categories be used. The categories can be defined by assigning the FILI values according to “sextiles” of the correspondent FILI distribution. Once the selected FILI values are assigned to the appropriate category, the corresponding cumulative frequencies can be computed and applied using the

VLI concept with frequency weighting. A computer program would be helpful in performing these computations.

## Procedure Details

*Collecting organizational and production data*. The study of organizational data is required for all types of lifting jobs including single-task, multitask, variable, or sequential lifting jobs. The first assessment step is identifying the number or workers involved in manual handling activities with substantially the same task characteristics, such as weights lifted and task geometries. Then the work/rest pattern for the job has to be assessed across the shift (i.e., determine the sequence and relative amount of time spent performing manual lifting tasks and other "nonmanual handling" activities and/or "breaks"). The various weights and relative number of objects lifted manually in a shift by one worker is then considered from production data. In order to simplify the weight variable, five WTCs are defined according to the following procedure. First, all of the weights to be lifted are listed in a table (for this procedure, consider weights from 3 kg up to maximum, by incremental steps of 1 kg). If there are more than five different weights, the weights are aggregated into a maximum of five WTCs by dividing the span of weight values (i.e., max. value – min.) by 5 to determine the min. and max. for each category. A representative average (by frequency) weight is selected for each category. An example of this aggregation process is shown in Table 4. The range of lifted weights is divided into five WTCs with equal intervals. Each of the individual lifts is then aggregated into those five categories, and the overall number of lifts in each category is determined. Finally, an average weight is computed for each WTC that will be used in subsequent computations.

From previous data such as "number of workers involved in the task(s)," "net duration of manual lifting in the shift," "total number of objects lifted during a shift," and "number of objects within each WTC lifted during a shift," one can determine the "overall" lifting frequency (per worker) and the "partial" lifting frequency for each WTC (as shown in Table 4 for a lifting duration of 300 minutes in a shift). These partial frequency values are then used in subsequent calculations, along with the appropriate lifting duration scenario (short, medium, and long), to determine the appropriate FMs from the traditional FM tables (for hands height < 75 cm.) (Waters et al., 1994).

*Simplification of geometry variables*. Another simplification will likely be needed to account for variability in task geometry among a large number of lifts. Colombini et al. (2009, 2012) have suggested guidelines for simplifying task geometry. The approach outlined by Colombini et al. provides for simplification of geometry by collapsing various factors into a small number of possible conditions, such as horizontal and vertical hand location, and task asymmetry.

The following simplifications were recommended:

*Vertical location* (height of hands at lifting origin or destination): This variable is reduced to two areas:

- Ideal area (good): Hands are between 51 and 125 cm vertical height; the VM is equal to 1.
- Nonideal areas (low or high): Hands are equal or below 50 cm or above 125 cm (up to 175 cm) vertical height; the VM is equal to 0.78.

In cases where the vertical height exceeds the maximum recommended vertical height (>175 cm), the lifts would be considered unsafe.

*Horizontal location* (maximum hand grasp point away from the body during lifting): The horizontal distances were simplified into three areas—near, mid, and far. The three distances are defined as follows:

- Near—Horizontal distance is within 25–40 cm; the representative HM is equal to 0.71 (for a representative value of 35 cm).
- Mid—Horizontal distance is within 41–50 cm; the representative HM is equal to 0.56 (for a representative value of 45 cm).
- Far—Horizontal distance is within 51–63 cm; the representative HM is equal to 0.40 (for a representative value of 63 cm).

In cases where the horizontal distances exceeds the maximum recommended value (>63 cm),

**TABLE 4:** Aggregation of Several Weights Lifted by a Worker During a Shift in Five WTCs and Computation of Correspondent Lifting Frequency: Example for Weights Ranging From 5 to 15 kg and for a Lifting Duration of 300 Min in a Shift

| | | Resulting Aggregated WTCs | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Weight (kg) | No. of Objects Lifted per Shift by a Worker | Cat. No. | From | To | No. of Objects in Category | Average Weight (for the Category) | Percent Objects in Category | Overall and Partial Frequencies (Lifts/Min) (Referred to 300 Min Lifting Duration) |
| 5 | 100 | | | | | | | |
| 6 | 80 | 1 | 5.0 | 6.0 | 180 | 5.4 | 31.0% | 0.60 |
| 7 | 70 | 2 | 7.0 | 8.0 | 170 | 7.6 | 29.3% | 0.57 |
| 8 | 100 | 3 | 9.0 | 10.0 | 110 | 9.5 | 19.0% | 0.36 |
| 9 | 50 | 4 | 11.0 | 12.0 | 90 | 11.6 | 15.5% | 0.30 |
| 10 | 60 | 5 | 13.0 | 15.0 | 30 | 13.7 | 5.2% | 0.10 |
| 11 | 40 | | | | | | | 1.93 (overall) |
| 12 | 50 | | | | | | | |
| 13 | 15 | | | | | | | |
| 14 | 10 | | | | | | | |
| 15 | 5 | | | | | | | |
| Total | 580 | | | | | | | |

| Min. Weight Value (a) | Max. Weight Value (b) | Difference (b – a) = c | Weight Δ (for 5 Categories) |
|---|---|---|---|
| 5 | 15 | 10 | 2 |

the lifts are considered unsafe (no computation is possible).

*Asymmetry* (angular displacement of loads off to the side of the body): Asymmetry is considered collectively for each WTC. An AM of 0.81 is assigned to all the subtasks in a WTC if asymmetry of 45° or more is observed for over 50% of lifting actions in that category. Otherwise the AM is set equal to 1.

*Vertical travel distance* (vertical distance between the height of hands at origin and at destination): The contribution of this factor has been considered as noninfluent. The CM has thus been taken as a constant, equal to 1. It should be underlined that even if the vertical DM is set as a constant, the height of the hands at both the origin and destination of the lift should always be measured and considered.

*Coupling* (quality or type of grip): The contribution of this factor has also been defined as constant. Experience has taught that "ideal couplings" are very rare, so the CM is defined as a constant equal to 0.90.

By adopting the simplifications and procedures proposed by Colombini et al. (2009, 2012), it is possible to analyze a "variable lifting task" scenario and produce up to (and no more than) 30 sets of FILI and STLI values, one for each of 30 different subtasks (5 WTCs × 2 Vertical Location × 3 Horizontal Areas × 1 Asymmetry Condition). After the FILI subtasks are determined from the data, the subtasks will be further classified into six "LI categories" and the VLI for the overall job will be determined. This approach is demonstrated in the example that follows.

*Example of systematic organizational analysis approach*. In a metal-working plant, workers load and unload plastic containers of in-process materials to and from assembly lines for processing. The task is organized in cycles; during each cycle, the worker handles various containers in different body postures due to different heights (of the hands) at the origin and destination and different horizontal distances. The shift lasts 480 min (from 8 a.m. to 5 p.m.). The work starts at 8 a.m., there is a break of 10 min at 10 a.m., and lunch time is at 1:10 p.m. (it lasts 60 min; out of official working time). In the afternoon, the activity is the same as in the morning with a 10 min break at 3.10 p.m. and the last 40 min devoted to "light work" (no manual handling). Hence the total manual handling duration during the shift is 420 net minutes. Table 5 shows the sequence of lifting task, breaks, and light work during the shift.

The containers have three different weights (6, 8, and 13 kg); the respective number of pieces lifted during the shift is shown in Table 6.

Because 1,852 containers are lifted during a 420-min period, the overall lifting frequency is 4.41 lifts per minute. The partial lifting frequencies for each type (weight) of container are as follows: 1.18 lifts/min for the 6 kg containers, 2.94 lifts/min for the 8 kg containers, and 0.29 lifts/min for the 13 kg containers. The duration for the job is categorized as "long duration" (continuous period of manual handling of 120 min + a break of "only" 10 min + 120 min of manual handling). The lifting activities are performed at different heights (of the hands) at the origin and destination and different horizontal distances; there is minimal lift asymmetry for all lifts (i.e., all objects are lifted in front of the body resulting in an asymmetry multiplier = 1.0), and the hand-to-object coupling is poor for all lifts (i.e., coupling multiplier = 0.9). A significant control is present for quite all lifting actions.

Data regarding the "geometries" at the origin and destination of the lifts, by WTC, is shown in Table 7.

In this scenario, it is not possible to use the traditional multitask lifting index (CLI) approach, as there would be up to 50 different individual FILI values (or about 122 if one considers both origin and destination). Also, the mean frequency of each type of lift would be very low (about 0.030–0.036 lifts/min). Because the traditional CLI approach cannot work, the proposed VLI approach, using weight and geometry simplifications, should be used to assess the task.

In the presented example, we have only three WTCs (6, 8, and 13 kg); each of them could have two "simplified" variants for "height of hands" (good and bad) at origin/destination; in turn, each of them could have one, two, or three "simplified" variants for horizontal distance (near, mid, and far). Because different horizontal distances per WTCs are clearly identified both at origin than at destination, it results in a total of 14 individual subtasks, as shown in Table 8. Table 8 also displays the corresponding weights, geometries, partial frequency, and FM, FILI, and STLI values for each of the 14 identified subtasks.

For determining partial frequencies of individual subtasks, a special procedure has been adopted that takes into account, for each WTC, how many times the "height of hands" starts or ends, respectively, in a "good" or "bad" area, considering small height intervals of 10 cm and then considering how many times each "height of hands" (good and bad) at origin/destination corresponds to different variants for horizontal distance (near, mid, and far) both at origin and at destination. This procedure is a little more complicated than simply assigning an equal frequency to all the combinations present in a WTC, but assisted by proper software, it is a better estimate of the different frequencies in different "geometries" combinations in a certain category. For example, for the 6 kg category, we could consider as equally represented all the six possible combinations ("height of hands," good/bad; "horizontal distance," near/mid/far) and consequently dividing the overall WTC frequency of 1.18 by 6, thus obtaining partial frequencies for each combination of 0.196.

However, it is preferable to adopt the more detailed procedure to obtain more accurate estimates of the partial frequencies of individual combinations. Using this procedure, we have that four of nine lifts (44.4%) originate or end in a bad vertical height (L/H vertical height) and the other five (55.6%) are in the good vertical height category. For the bad vertical height cat-

**TABLE 5:** Sequence and Duration of Lifting Task, Light Work, and Breaks for the Case Study in an 8-Hr Shift

| Sequence and Duration (in Minutes) of Tasks During the Shift | Manual Lifting Task | Other Light Task or Break | Manual Lifting Task | Other Light Task or Break | Manual Lifting Task | Other Light Task or Break | Manual Lifting Task | Other Light Task or Break |
|---|---|---|---|---|---|---|---|---|
| Minutes | 120 | 10 | 120 | 60 | 120 | 10 | 60 | 40 |
| Shift starts / ends at | Start: 08:00 | | | | | | | End: 17:00 |
| Notes | | Break | | Lunch | | Break | | |
| Time in the shift | 08:00–10:00 | 10:00–10:10 | 10:10–12:10 | 12:10–13:10 | 13:10–15:10 | 15:10–15:20 | 15:20–16:20 | 16:20–17:00 |

**TABLE 6:** Type of Weights and Number of Containers Lifted by the Worker During an 8-Hour Shift and Consequent Lifting Frequency per Type of Weight

| No. of Containers | Weight | Frequency of Lifts/Min |
|---|---|---|
| 494 | 6 kg | 1.18 |
| 1,235 | 8 kg | 2.94 |
| 123 | 13 kg | 0.29 |
| 1,852 | All containers | 4.41 |

**TABLE 7:** Data Regarding Load and Geometry Characteristics

| Load characteristics | | Origin | | Destination | | |
|---|---|---|---|---|---|---|
| *N* | Weight | Vertical Height Above Floor | Horizontal Distance | Vertical Height Above Floor | Horizontal Distance | No. of Potential Subtasks Derived |
| 494 | 6 kg | 8 levels from 14 to 84 cm | 35, 45, and 55 cm | 80 cm | 30 cm | 24 |
| 1,235 | 8 kg | 4 levels from 80 to 110 cm | 30 cm | 8 levels from 14 to 84 cm | 35, 45, and 55 cm | 96 |
| 123 | 13 kg | 2 levels, at 30 and 50 cm | 45 cm | 80 cm | 30 cm | 2 |

egory, the lifts will be equally distributed with regard to horizontal reach (i.e., one third of the lifts will be near, one third mid, and one third far reaches), whereas for the good vertical height category we have one half of the lifts in a near horizontal reach and one fourth, respectively, in the mid and far reach categories. Therefore, for the combinations L/H-Near, L/H-Mid, and L/H-Far, the prevalence (with respect to all the 6 kg lifts) of lifts result always of about 14.8% each; because the overall frequency of lifts in the 6 kg category is 1.180 lifts per minute, we have for each combination a partial frequency of about 0.175 lifts per minute. For the combinations of good-near, good-mid, and good-far, the prevalence (with respect to all the 6 kg lifts) of lifts result, respectively, in 27.8%, 13.9%, and 13.9% and the corresponding partial frequencies are 0.328, 0.164, and 0.164.

For the other WTCs, a similar approach has been used to determine individual tasks partial frequencies.

The resulting frequencies of lifts for the various combinations (14 in the present example) of vertical height and horizontal reaches are reported in Table 8.

Because 14 subtasks are still too many to use directly the CLI formula, it is advisable to use the VLI concept and approach. To apply the VLI approach, subtasks and corresponding data (FILI, frequencies, and STLI) are distributed into six LI categories. Those six categories are determined according to the distribution of the individual FILI values (in this case 14 values) using preferentially the sextile distributions as key points for grouping (or in other terms the values corresponding to the 16.6th, 33.3rd, 50th, 66.6th, and 83.3rd percentile of the resulting FILI distribution). As a simpler alternative, one may obtain six key points by dividing the range of FILI values (i.e., maximum FILI – minimum FILI) divided by 6; this simpler option has, however, some disadvantages (i.e., some LI category could be empty; the distribution of FILI values could be not well represented). In any case, the original frequencies of individual subtasks (14 in present case) are grouped and cumulated in the six "LI categories." Single (category) LI values could be consequently computed and used for reordering (from highest to lowest) the six "LI categories."

Within each resulting "LI category," a representative FILI value is chosen: This value is the highest for the highest category (category number 1); it corresponds to the mean (central) value for all the other five LI categories.

Tables 9 and 10 display details of this procedure according to the previous example.

Using these data, organized in six FILI categories, it will be possible to compute the VLI by means of the traditional CLI formula in the same way previously reported for the task sampling approach.

Based on the data presented for this example, the computational data for applying the formula $VLI = STLI_1 + \sum \Delta LI$ are reported in Table 11.

Using data reported in Table 11, the VLI for this job can be calculated, as follows:

$$VLI = STLI1 + \sum \Delta LI$$
$$STLI1 = 1.656$$

$$\Delta FILI2 = 0.907 * \left[(1/0.698) - (1/0.748)\right]$$
$$= 0.907 * (0.096) = 0.087$$

**TABLE 8:** Data Regarding the 14 Resulting Subtasks (and Corresponding FILI and STLI) by Applying the Simplifications and the Frequency Estimation Procedures

| Subtask | Weight (kg) | Vertical Height Classification and VM | | Vertical Dislocation (DM = 1; Constant) | | Horizontal Distance Classification and HM | | Asymmetry | | Type of Grasp (CM = 0,9; Constant) | | FIRWL | FILI | Frequency (Rounded) | Duration Scenario and FM | | STLI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6 | L/H | 0.78 | G | 1.00 | N | 0.71 | A | 1.00 | P | 0.90 | 11.5 | 0.523 | 0.17 | LD | 0.850 | 0.62 |
| 2 | 6 | L/H | 0.78 | G | 1.00 | M | 0.56 | A | 1.00 | P | 0.90 | 9.0 | 0.664 | 0.17 | LD | 0.850 | 0.78 |
| 3 | 6 | L/H | 0.78 | G | 1.00 | F | 0.40 | A | 1.00 | P | 0.90 | 6.5 | 0.929 | 0.17 | LD | 0.850 | 1.09 |
| 4 | 6 | G | 1.00 | G | 1.00 | N | 0.71 | A | 1.00 | P | 0.90 | 14.7 | 0.408 | 0.33 | LD | 0.833 | 0.49 |
| 5 | 6 | G | 1.00 | G | 1.00 | M | 0.56 | A | 1.00 | P | 0.90 | 11.6 | 0.518 | 0.16 | LD | 0.850 | 0.61 |
| 6 | 6 | G | 1.00 | G | 1.00 | F | 0.40 | A | 1.00 | P | 0.90 | 9.3 | 0.725 | 0.16 | LD | 0.850 | 0.85 |
| 7 | 8 | L/H | 0.78 | G | 1.00 | N | 0.71 | A | 1.00 | P | 0.90 | 11.5 | 0.698 | 0.33 | LD | 0.833 | 0.84 |
| 8 | 8 | L/H | 0.78 | G | 1.00 | M | 0.56 | A | 1.00 | P | 0.90 | 9.0 | 0.885 | 0.33 | LD | 0.833 | 1.06 |
| 8 | 8 | L/H | 0.78 | G | 1.00 | F | 0.40 | A | 1.00 | P | 0.90 | 6.5 | 1.239 | 0.33 | LD | 0.833 | 1.49 |
| 10 | 8 | G | 1.00 | G | 1.00 | N | 0.71 | A | 1.00 | P | 0.90 | 14.7 | 0.544 | 0.98 | LD | 0.752 | 0.72 |
| 11 | 8 | G | 1.00 | G | 1.00 | M | 0.56 | A | 1.00 | P | 0.90 | 11.6 | 0.690 | 0.49 | LD | 0.811 | 0.85 |
| 12 | 8 | G | 1.00 | G | 1.00 | F | 0.40 | A | 1.00 | P | 0.90 | 8.3 | 0.966 | 0.49 | LD | 0.811 | 1.19 |
| 13 | 13 | L/H | 0.78 | G | 1.00 | N | 0.71 | A | 1.00 | P | 0.90 | 11.5 | 1.134 | 0.20 | LD | 0.850 | 1.33 |
| 14 | 13 | G | 1.00 | G | 1.00 | N | 0.71 | A | 1.00 | P | 0.90 | 14.7 | 0.885 | 0.10 | LD | 0.850 | 1.04 |

*Note*. A = absent; CM = coupling multiplier; DM = distance multiplier; F = far; FILI = frequency independent lift index; FIRWL = frequency independent recommended weight limit; FM = frequency multiplier; G = good; HM = horizontal multiplier; LD = long duration; L/H = low or high; M = medium; N = near; P = poor; STLI = single task lifting index; VM = vertical multiplier.

**TABLE 9:** Identification of Key Points by the "Sextile" Approach Using the FILI Data Distribution From Table 8

| | First Key Point—16.66th Percentile | Second Key Point—33.33th Percentile | Third Key Point—50th Percentile or Median | Fourth Key Point—66.66th Percentile | Fifth Key Point—83.33th Percentile | Sixth Key Point—Maximum Value |
|---|---|---|---|---|---|---|
| Key value | 0.527 | 0.672 | 0.711 | 0.885 | 0.960 | ($FILI_{max}$) 1.239 |
| LI category range | 0.408–0.526 | 0.527–0.671 | 0.672–0.710 | 0.711–0.884 | 0.855–0.959 | 0.960–1.239 |

*Note.* FILI = frequency independent lift index; LI = lifting index.

**TABLE 10:** Relevant Values for Each FILI Category Using the Key Points From Table 9 and the Consequent Cumulated Frequencies Derived From Table 8

| Category Data | FILI CAT (<16.66) | FILI CAT (16.66–33.33) | FILI CAT (33.33–50) | FILI CAT (50–66.66) | FILI CAT (66.66–83.33) | FILI CAT (>83.33) |
|---|---|---|---|---|---|---|
| Range of FILI values | 0.408–0.526 | 0.527–0.671 | 0.672–0.710 | 0.711–0.884 | 0.855–0.959 | 0.960–1.239 |
| Representative category FILI value | 0.483 | 0.604 | 0.694 | 0.805 | 0.907 | 1.239 |
| Number of subtask in each category | 3 | 2 | 2 | 2 | 2 | 3 |
| Cumulative frequency (lifts/min) within the category | 0.66 | 1.15 | 0.82 | 0.26 | 0.50 | 1.02 |
| FM values (long duration) | 0.791 | 0.735 | 0.772 | 0.842 | 0.810 | 0.748 |
| STLI (category) value | 0.611 | 0.822 | 0.899 | 0.956 | 1.12 | 1.656 |
| Order by STLI value | 6 | 5 | 4 | 3 | 2 | 1 |

*Note.* FILI = frequency independent lift index; FM = frequency multiplier; STLI = single task lifting index.

$$\Delta FILI3 = 0.805 * \left[(1/0.672) - (1/0.698)\right] = 0.805 * (0.055) = 0.045$$

$$\Delta FILI4 = 0.694 * \left[(1/0.590) - (1/0.672)\right] = 0.694 * (0.207) = 0.144$$

$$\Delta FILI5 = 0.604 * \left[(1/0.475) - (1/0.590)\right] = 0.604 * (0.410) = 0.248$$

$$\Delta FILI6 = 0.483 * \left[(1/0.409) - (1/0.475)\right] = 0.483 * (0.340) = 0.164$$

$$VLI = STLI1 + \Delta FILI2 + \Delta FILI3 + \Delta FILI4 + \Delta FILI5 + \Delta FILI6$$

$$VLI = 1.656 + 0.087 + 0.045 + 0.144 + 0.248 + 0.164 = 2.34.$$

The final VLI value for the present example is 2.34.

## DISCUSSION

The scientific basis for the VLI procedure is similar to that for the CLI originally presented

**TABLE 11:** Relevant Data for Computing Final VLI Derived From Table 10

| Connotation of Cumulative Frequencies by STLI Order | Cumulative Frequencies of Categories (Lifts/Min) | Corresponding FM (Long Duration) | Partial Value $[(1/FM_J) - (1/FM_{J-1})]$ | FILI | $STLI_1$ and $\Delta\ FILI_J$ |
|---|---|---|---|---|---|
| $FM_1$ | 1.02 | 0.748 | | 1.239 | 1.656 |
| $FM_{1,2}$ | 1.52 | 0.698 | 0.096 | 0.907 | 0.087 |
| $FM_{1,2,3}$ | 1.78 | 0.672 | 0.055 | 0.805 | 0.045 |
| $FM_{1,2,3,4}$ | 2.60 | 0.590 | 0.207 | 0.694 | 0.144 |
| $FM_{1,2,3,4,5}$ | 3.75 | 0.475 | 0.410 | 0.604 | 0.248 |
| $FM_{1,2,3,4,5,6}$ | 4.41 | 0.409 | 0.340 | 0.483 | 0.164 |

*Note*. FILI = frequency independent lift index; FM = frequency multiplier; STLI = single task lifting index; VLI = variable lifting index.

by NIOSH in the *Applications Manual for the Revised NIOSH Lifting Equation* (Waters et al., 1994). The CLI was based on the assumption that the physical stress for a multitask manual lifting job with multiple lifting tasks would be greater than the physical stress for the task element with the greatest single STLI and that the overall physical stress would increase as additional tasks were added to the job. Thus, the CLI started with the task with the greatest single STLI and then each successive task was added into the CLI calculation based on increasing FILI value. The frequency adjustments were added into the formula during the final summation of the physical stress measure to account for the physiological demand of the job that would result from the frequency and duration of the overall job. The scientific logic for the VLI as an assessment method should be similar to that for the CLI and SLI methods that have previously been proposed by NIOSH development teams (Waters et al., 1994; Waters et al., 2007). The exact cut-off or threshold values used with the categorization strategy remains problematic with the RNLE. Validation studies should help to clarify and refine it.

The FILI measure for each task in a multitask job was designed to provide some idea about what the biomechanical risk for the task would be independent of the other tasks being performed or their frequencies. In this way, the user would be able to identify those job tasks that would be best addressed by adjusting the job characteristics to maximize the reduction in biomechanical stress. The VLI procedure is based on a similar principle. The difference is that a specific set of job categories are created to allow inclusion of all the lifts in order to emulate the individual tasks in the CLI procedure. Rather than use specific values for the FILI, each job category is composed of a range of FILI values that correspond to a level of biomechanical stress. From this perspective, individual lifts with high physical demands cannot be identified, but categories containing tasks with the highest physical demands would likely be identified from the VLI analysis. In this way, two distinct jobs with variable task characteristics can be compared and the categories with the highest physical demand can be identified and adjusted by reducing exposure to those tasks comprising the category with the highest physical demand as determined from the VLI analysis. The question may arise as to the handling of tasks where the measured task parameters are outside of the allowable range (e.g., a horizontal distance beyond 63 cm or a vertical height above 175 cm). In this case, the particular task should be defined as "critical" with the suggestion that an urgent redesign intervention is needed. As a second option, the analyst may choose to use the maximum multiplier for the parameter (e.g., the HM of 0.4 for a 63 cm horizontal distance used for horizontal distances greater than 63 cm), with the understanding that the risk may be underestimated. In these types of cases, the analyst may also consider supplementing the RNLE analysis with other analysis methods.

## CONCLUSION

The VLI method allows an analyst to assess highly variable manual lifting jobs in which the task characteristics vary from lift to lift during a shift. The VLI can also provide an overall assessment of the physical demands for manual lifting jobs performed in environments where traditionally it has been difficult to assess. As with the previous SLI method (Waters et al., 2007), it is critical that the VLI method is validated using an epidemiological approach to investigate the association between LI (CLI and VLI) values and health outcomes. The preliminary results of such a study are presented in this special issue (Battevi, Pandolfi, & Cortinovis, in press).

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## KEY POINTS

- Variable lifting task is defined as a lifting task in which both the load displacement/geometry and load mass vary in different lifts performed by the worker(s) during the same period of time (i.e., an 8-hour shift).
- A variable lifting task is often observed in industry, warehousing, baggage handling, construction, and several service jobs, but a procedure for analyzing variable lifting tasks has not been previously defined by NIOSH.
- A procedure for computing the VLI, based on adaptations of the RNLE and of the Composite Lifting Index approach is presented as a practical tool for analyzing variable lifting tasks.
- The procedure is aimed at compressing a potential high number of individual Lifting Indexes to a restricted number to better apply the CLI formula.
- There are two different approaches for obtaining the data needed to apply the VLI procedure: the "sampling approach" and the "systematic organizational analysis approach." They are both presented with applicative examples.
- The VLI approach is now addressed by International Organization for Standardization (ISO) technical report (TR) 12295 as a practical tool for the application of the ISO standard 11228-1.
- Free downloadable software are available at www.epmresearch.org to apply the procedure and compute the VLI.

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