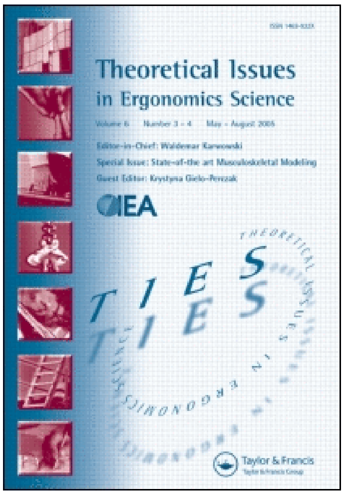

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# Human posture simulation to assess cumulative spinal load due to manual lifting. Part I: methods

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The estimation of cumulative spinal load (CSL) resulting from exposure to manual materials handling (MMH) may provide a sensitive method for assessing the risk of highly varying exposures. This article reports on a CSL method that involves human posture simulation of workers from videotape in order to assess spinal load exposures due to MMH. The proposed method appears to be sensitive to different durations of exposure, easy to use and useful for assessing jobs with a high degree of variability in task characteristics between lifts. Although the method remains to be validated, it appears to be a useful addition to the range of tools available for assessing manual lifting exposures in worksite-based epidemiologic studies. Ergonomic methods are lacking for assessing highly variable MMH tasks, such as tasks found in warehousing. The existing methods do not include sufficient factors to account for variable exposure patterns or tasks with highly variable task characteristics, such as varying load weights and lift geometries. The CSL assessment method described in this article may provide a way to evaluate these types of tasks in order to assess the overall risk of workers developing work-related musculoskeletal disorders.

**Keywords:** human posture simulation; cumulative spinal loading; manual lifting; NIOSH Lifting Equation

## 1. Introduction

Numerous methods have been developed to assess risk factors for occupational low back disorders (LBDs) due to manual materials handling (MMH), such as the National Institute for Occupational Safety and Health (NIOSH) Lifting Equation, the Ohio State University (OSU) Lumbar Motion Monitor-based Low Back Disorder (LBD) risk model and the University of Michigan 3D Static Strength Prediction Program (3DSSPP) Model. For the most part, all these methods suffer from a lack of ability to differentiate between jobs performed for varying periods of time. For example, the University of Michigan 3DSSPP model lacks any capability to include lift frequency or duration in the assessment of risk. The OSU Lumbar Motion Monitor-based LBD risk model does have a variable for lift rate, but it lacks any variable for the length of exposure to lifting stressors (Marras *et al.* 1993, 1995). In comparison, the NIOSH Lifting Index (LI) does provide

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a variable for lift frequency and duration, but the duration variable is limited to only three categories (1, 1–2 and 2–8 h), limiting its ability to differentiate between jobs with highly varying exposure patterns. The assessment methods based on calculation of cumulative spinal loading (CSL) would appear to better account for varying exposure patterns over time, but they are generally complex and time consuming to use.

This article describes a new method for assessing risk factors that allows the analyst to obtain information from a large number of lifting tasks in order to estimate risk of LBDs. The method can be used to determine CSL over a specified period of time, as well as the Revised NIOSH Lifting Equation (RNLE) values for lifting tasks. The magnitude of CSL resulting from exposure to MMH activities has been shown to be a significant predictor of risk of LBDs (Kumar 1990, Norman *et al.* 1998, Callaghan *et al.* 2001). In 2006, Waters and colleagues published an extensive review of CSL methods and conducted a meta-analysis of the results to evaluate whether CSL metrics were useful in predicting the risk of LBDs (Waters *et al.* 2006a). Based on four major published studies that were considered relevant, Waters *et al.* (2006a) calculated a meta-odds ratio for LBD outcomes to be 1.66 (95% confidence interval using quality scores = 1.46–1.89; $p \leq 0.05$). In other words, workers with LBDs were more than one and one-half times more likely to have been exposed to high levels of CSL compared to those who did not experience LBDs. Based on these findings, the authors concluded that '…there likely is an association between cumulative spinal loading and LBD' (Waters *et al.* 2006a).

In 2006, Waters *et al.* published a second paper outlining the methodological issues and applicability of the CSL method for use in epidemiological studies (Waters *et al.* 2006b). In that paper, Waters and colleagues identified four major methodological issues that must be considered when calculating CSL estimates. These include: (1) determining the method used to estimate, capture, or sample the postures and hand loads; (2) approaches used to estimate the magnitude of spinal loads; (3) method used to integrate the loads over time due to repeated biomechanical loads and (4) type of estimated biomechanical parameters produced by the assessment method. The following is a brief description of previous studies that have used CSL to measure loading on the spine due to MMH.

In a study of CSL, Kumar (1990) used a recall interview of postures that people were exposed to and then interpolated postures between these recalled positions to produce 0.2 s interval posture estimates (5 Hz). A model was then run on these generated postures to yield a frame-by-frame evaluation of the disc compression force (DCF) and shear force (SF) values for each frame, which were then integrated. Norman *et al.* (1998) used motion analysis to derive the peak static spinal load and multiplied these values by the number of repeats and duration of each task to yield a shift exposure (Daynard *et al.* 2001, Kerr *et al.* 2001). In the Dortmund Lumbar Load Study (DOLLY), Jäger *et al.* (2000) employed a postural sampling approach and a biomechanical model to calculate load for an entire shift and then extrapolated the data to yield results for longer time periods. Three weighting systems were used for force relative to exposure time to calculate shift dose. The Mainz–Dortmund dose model (MDD) is based only on the events when the lumbar disk compression force exceeds 3.2 kN and the standardised durations of the lifting process (Jäger *et al.* 2000). Mirka *et al.* (2000) examined time-weighted histograms of different construction jobs using a 3D static biomechanical model, NIOSH LI and the Lumbar Motion Monitor©. Their findings indicated that the different techniques yielded different results. Callaghan *et al.* (2001) analysed lifting tasks using five documenting approaches that included (1) rectangular integration with a sample rate of 5 Hz, (2) spinal loading at the initiation of the lift multiplied by the duration of the task, (3) cycle divided into work and rest, (4) the work phase of the cycle and (5) cycle divided into four work components, and compared them to a 'gold standard', the biomechanical model outputs for the entire lifting cycle (i.e. all frames at 30 Hz) and concluded there were significant errors (average error between task and subject was 27–69%) for four of the approaches that used discrete measures to represent the time-varying cyclic exposure. Sullivan *et al.* (2002) examined inter- and intra-observer reliability of calculating lumbar spine loads. The results showed that compression and moment demonstrated the highest reliability in comparison to joint force and reaction shear. Andrews and Callaghan (2003) investigated the minimum sampling rate needed to accurately quantify CSL. It was found that the mean relative errors with respect to 60 Hz for all cumulative loads and conditions were found below 8% at 1 Hz, and less than 3% at 2 Hz. Seidler *et al.* (2001, 2003) investigated the relationship between lumbar spine disease and cumulative occupational exposure to lifting or carrying and to working postures with extreme forward bending using a case-control study design. They employed structured questionnaires and interviews to extract data on postures and loads, and used one of the three algorithms described by Jäger *et al.* (2000) for cumulative compressive loading (Seidler *et al.* 2001, 2003). Additionally, Stuebbe *et al.* (2002) used a work sampling approach to collect postural data for compressive force calculation. The cumulative load in Stuebbe *et al.*'s (2002) study was computed as the sum across all samples.

The CSL-based approaches would be well suited to assessing LBD risk for tasks with varying exposure patterns. For example, as can be seen in Figure 1, there are clear differences in assessing exposure to manual lifting stressors between the NIOSH LI and the CSL metrics. If the LI for Job 1 = 2.0 in Figure 1, then the LI for Jobs 2 and 3 would also be 2.0. In comparison, if the CSL for Job 1 is 1000 N min, then the CSL for Job 2 would be 2000 N min and the CSL for Job 3 would 6000 N min. Based on these hypothetical numbers, it is clear that the three jobs shown in Figure 1 have significantly

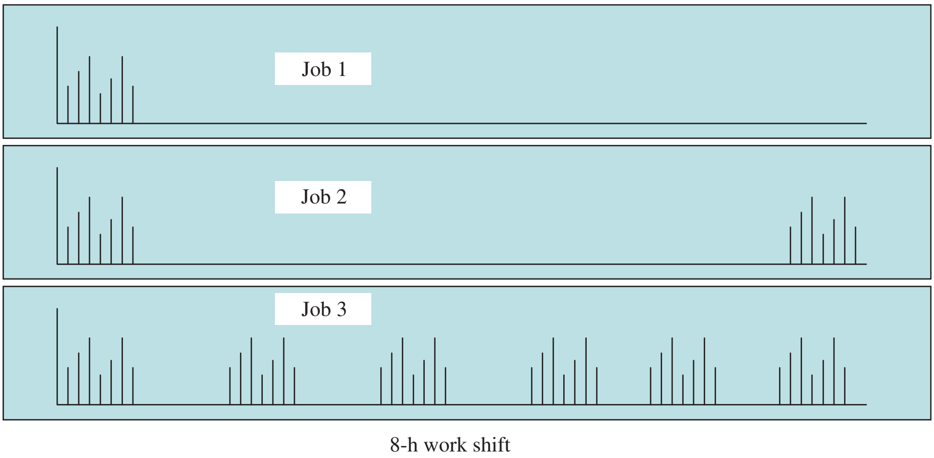

Figure 1. Comparison of NIOSH LI to CSL for three hypothetical lifting jobs. Each tick mark represents the magnitude of CSL for an individual lift (i.e. peak DCF times the duration of the lift). Each ½ h segment of lifting (shown as a cluster of tic marks of varying magnitude) is the same for each of the three jobs above. Job 1 is done for only ½ h total, Job 2 is done for ½ h in the morning and ½ h in the afternoon and Job 3 is done every ½ h with ½ h rest breaks separating lifting sessions.

different levels of CSL, but the NIOSH LI value for each job would be the same and the NIOSH LI method would not be sensitive to the differences in the total physical exposures over the course of the shift.

Unfortunately, there is a gap in exposure assessment methodology and an easy to use CSL-based method that does not require extensive time-consuming sampling of hand forces and task variables for all of the lifts to be analysed, is needed.

The purpose of this article is to describe a human posture simulation-based exposure assessment method for examining the relationship between exposure to spinal loading (i.e. loading due to both repetitive MMH and postural loading), and risk of self reported low back pain in an epidemiological study of manual lifting that is currently being conducted by NIOSH. The proposed method provides a single estimate of the total cumulative load due to repeated MMH and postural stress. This article describes how the proposed model addresses the four primary CSL design issues previously mentioned (Waters *et al.* 2006b). The proposed method is similar to the approach described by Callahagan *et al.* (2001), in which the spinal loading at the initiation of the lift is multiplied by the duration of the task. In order to obtain this information for each lift, the posture and static hand load information at the origin of the lift and the time between the origin and destination of the lift is required. The human posture simulation-based method is described below.

## 2. Methods

The method consists of collecting posture data from an instrumented simulator who is posing in postures observed from videotape of actual work tasks. Each lift is assessed individually by identifying the origin of the lift (i.e. frame in which the load initially begins to move upward) and the destination of the lift (i.e. frame in which the load stops moving downward). The posture data are collected at the origin of the lift and the time between the origin and the destination of the lift is determined. The posture data, at the origin and destination of the lift, are used to calculate the input variables for applying the University of Michigan 3DSSPP (Chaffin *et al.* 1999) and the RNLE for a series of manual lifting tasks. The input variables for the 3DSSPP include 15 body angles (angles describing the position of the legs, trunk, torso, arms), worker gender, height and body weight. The output from the 3DSSPP includes the L5/S1 DCF, anterior–posterior shear force (APSF), lateral shear force (LSF) and net moment about the L5/S1 joint. The variables needed to use the RNLE include horizontal distance (H), vertical distance (V), vertical displacement (D) and asymmetry angle (A). The remaining variables needed for the RNLE (duration category, task frequency and hand-to-object coupling type) are input by the analyst or calculated from the videotape sequencing. The posture data are obtained from the human posture simulation using a digital motion capture system and is input into custom software in order to calculate the required input variables for the 3DSSPP and NLE programmes.

The procedure consists of the following steps:

(1) Videotaping the desired MMH tasks at the worksite and obtaining information about the weights and forces handled, as well as the workers' height and weight.
(2) Pre-screening the videotapes to identify the specific frame numbers that correspond to the origin (lift-off) and destination (set-down) point for each lift of interest over the specified period of interest.

(3) Simulating and capturing the postures for the worker at each of the identified lifting points using a human simulation method and a motion capture system. The human simulation method consists of projecting the desired still images on a large screen visible to the simulator who then mimics the observed posture on the screen. When the simulator has adjusted her/his posture to match that on the screen the data are recorded by the motion capture system.
(4) Translating the motion capture data into an input file that can be read by the University of Michigan 3DSSPP and a customised NIOSH programme used to calculate the RNLE parameters.
(5) Calculating the spinal loading parameters of interest for each lift (DCF, APSF, LSF and net moment about the L5/S1 joint,) and lift duration times (time between the lift-off and set-down point).
(6) Calculating the individual cumulative load contribution (ICLC) for each lift by multiplying the spinal load parameter for that lift times the duration time for that lift.
(7) Calculating the overall cumulative load for an entire shift by adding up all of the ICLC values for each lift performed during the shift.

Detailed information on each step is provided as follows:

### 2.1. *Step 1 – Videotaping*

Jobs are videotaped in the field for later analysis in the laboratory. The job is videotaped from various angles for every lift performed over a fixed time period (usually about 15 min for each videotaping session, depending upon the variability of the task characteristics within the job). The video camera operator is required to position the camera such that the position of the feet and hands are always in the field of view during the lifting activities of interest. The weights of the objects lifted are also recorded if the weight varies between lifts. Although there may be more than one session of videotape from each worker doing the same job and from different angles, each session of videotape is analysed separately and each lift within each session is assessed separately. Therefore, input is not required from more than one videotape and there is no need to synchronise various cameras or taped sessions.

### 2.2. *Step 2 – Pre-screening*

Since the simulator only needs to simulate the posture observed at two points during each lift (origin and destination), it is only necessary to present these two frames to the simulator for simulation for each lift. Although the two lifts can be identified during the simulation session itself, in order to save time while the simulator is instrumented with the motion capture system, a pre-screening of the videotaped sessions was performed by an analyst to identify the specific frame numbers corresponding to the origin and destination for each lift. This saves time during the simulation phase, since the simulator does not have to wait for the computer operator to identify the lift-off and set-down point, but rather can just display the proper frames that were identified during the pre-screening step.

### 2.3. *Step 3 – Simulating and posture capturing*

A system for simulating and capturing posture for ergonomic analysis was developed in our laboratory. The system consists of a simulation platform, a large display screen and

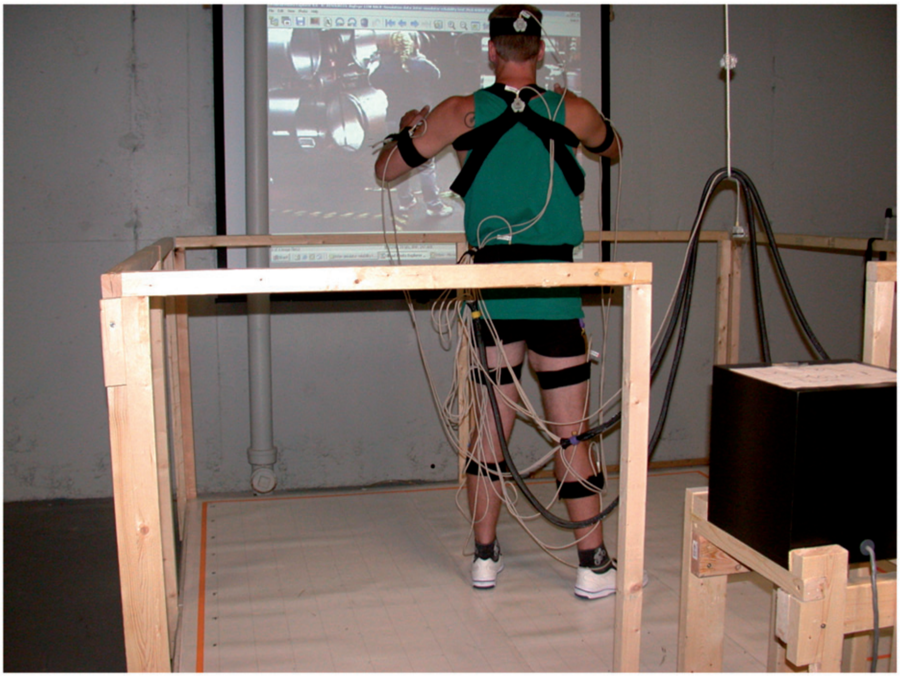

Figure 2. Set up for Motion Capture System (Ascension Technology Co, Flock of Birds Motion Star (1999) Burlington, VT).

an LCD projector, a magnetic-based motion capture system (Ascension Motion Star, Burlington, VT), and a link segment modelling software for calculating body angles and posture variables (Innovative Sports, Chicago, IL, USA). The system is shown in Figure 2. The motion capture system is capable of determining the position and orientation of the body segments by transmitting a pulsed DC magnetic field that is simultaneously measured by all sensors located within 3 m of the transmitter. From the measured magnetic field characteristics, the system independently computes the position and orientation of each sensor which is subsequently sent to the motion capture software programme (Motion Monitor, Innovative Sports Inc.). The position and orientation data are further processed with a link segment model for calculating the posture variables needed for use by 3DSSPP and RNLE.

A raised $2.4 \times 2.4\,\mathrm{m}^2$ wooden platform was used to elevate the working area to avoid any interference caused by metal objects in the floor. Wooden handrails (1.1 m in height) were constructed to surround the edges of the platform for fall protection. The transmitter was placed behind the platform, approximately 0.1 m away from the edge of the platform. The area of the platform was used for postural simulation. Posture to be simulated is displayed on a large projection screen approximately 2 m in front of the simulator.

A trained simulator is fitted and instrumented with the posture analysis system. Training consists of having the potential simulator perform a number of simulations from videotape. The authors judge that the simulator is sufficiently trained and qualified to simulate when the authors observe that the simulator is able to consistently replicate observed body postures based on foot and body positions.

The simulator is then presented with the various frames from the digitised video images of the lifting activity in order to capture the posture of the worker being observed. The simulator makes every attempt to use key visual indicators within the field of view to mimic or duplicate the posture observed. Because we were primarily interested in posture and because the height of the simulator could impact upon the posture being simulated, the simulator was matched to the height of the person being simulated. We did not attempt to match the weight, gender or age of simulator to the weight, age or gender of the person being simulated, because we believed these factors would have much less effect on the simulated posture. The simulation usually proceeds from the feet up. Once the feet are aligned to match the videotaped image, then the legs, hips, upper body, arms, etc. are moved into position to match the posture observed on the screen. The simulator may make as many adjustments as necessary to get into a matching position. Once the simulator feels they are in the best matching posture, they inform the computer operator, who stores a 3 s sample of the fixed posture. This process is performed for the origin and destination of each lift of interest. The data from the origin of the lift are used in the calculation of the 3DSSPP variables and the time between the origin and destination frames is used for the cumulative load calculation. The data from both the origin and destination of the lift are used to calculate the RNLE variables discussed later. Once the simulations are complete for a single session, the data are stored to the hard drive of the computer for later analysis. As noted above, the simulator was trained to simulate viewed postures. A follow-on paper by Lu *et al.* (2010) discusses the accuracy and reliability of the methods used for obtaining the posture data for the lifts. Briefly, we believe that the training was sufficient and that the postural measurement method is accurate, with average posture simulation error ranging from 1.7° to 8.5° for trunk flexion, which is generally smaller than errors reported in other studies requiring postural measurements (see Part II paper by Lu *et al.* 2010).

The Motion Monitor programme processes body position and orientation data to determine orthopaedic body angles (trunk flexion, trunk lateral bending, trunk axial rotation, left and right upper arm vertical and horizontal angles, left and right lower arm vertical and horizontal angles, left and right upper and lower leg vertical angles) required for calculating the 15 3DSSPP angular input variables and the four RNLE parameters (horizontal distance, vertical height, vertical displacement and asymmetry angle). The definitions of the 3DSSPP body angles can be found in the 3DSSPP manual (The Regents of University of Michigan 2001). The definitions of the four RNLE parameters are summarised below (Waters *et al.* 1993)

- $H$: distance between the mid point of the hands and the mid point of the ankles on the horizontal plane
- $V$: vertical distance between the floor and the mid point of the hands
- $D$: absolute difference in height between V-origin and V-destination of the lift
- $A$: angle between the body neutral line (perpendicular to the pelvis on the horizontal plane) and the line connecting the mid point of the hands and mid point of ankles on the horizontal plane.

The use of a complex motion capture system to obtain static postural data for each lift, such as the one used in this study, may seem to be an under-utilisation of this technology. Since it is not possible to replicate the dynamics of the lift during a simulation, however, and since the use of such a system to capture the whole body static geometry is quick, accurate and simple, we thought it would simplify data collection for the large number of lifts required for an epidemiological study.

### 2.4. *Step 4 – Translating the motion capture data*

In order to use the motion capture data as input for the analysis programmes (RNLE, 3DSSPP), the posture data are translated into the input parameters for the analysis programmes (15 3DSSPP body angles and the four required RNLE parameters) using the programmining capabilities of the Motion Monitor software. The input parameters are then imported into a custom software programme, where information regarding each simulated lifting activity, such as load weight and number of hands used, as well as the height and weight of the person simulated are manually entered in order to calculate the spinal loading and the RNLE parameters. This step can be executed either for data from one simulated lifting activity or a series of simulated lifting activities during a known work time period. For a series of simulated lifting activities, the custom programme generates a batch file for importing to the 3DSSPP to obtain spinal loading data for each individual lifting activity in a batch process. The 3DSSPP-generated spinal loading data for all lifting activities are stored in a single file that is subsequently imported to the custom programme for calculating CSL for the known work time period.

### 2.5. *Step 5 – Calculating spinal load parameters and RNLE values*

#### 2.5.1. *CSL calculations*

The cumulative load contribution for each lift is calculated as follows: (1) the spinal load parameters, including the DCF, sagittal moment, and lateral moment, at the L4/L5 spinal joint at the lift-off point for each lift using the 3DSSPP output and (2) the lift load time. The lift load time for each lift is calculated by counting the number of frames elapsed between the lift-off frame (frame captured for the origin point for the lift) and set-down frame (frame taken as the destination point for the lift). The cumulative spinal DCF and moments are then calculated for each lift by multiplying the spinal load parameters times the lift load time. These values represent the cumulative load parameters for each individual lift. Once the cumulative load parameters for each lift are calculated, the overall cumulative load parameters are computed by adding all of the individual estimates for each of the lifts. The overall cumulative load value can be calculated for any time duration, such as by the minute, hour, day, week, month, year or job position. The determination of the individual cumulative load per lift is based on a significant assumption that the area under the curve defined by the dynamic spinal load parameters plotted as a function of time would be the equivalent to the peak static load at the lift-off point multiplied by the time the spine was loaded (time differential between the lift-off and set-down points). This is graphically illustrated in Figure 3. As can be seen from the graph in Figure 3, the approach of multiplying the peak static load at the lift-off point by the spinal loading duration likely over and under-predicts the cumulative dynamic load during the course of the lift. In some cases, the over- or under-prediction may cancel itself out, so that the simple static method would be nearly equivalent to the dynamic method. In other cases, the static approach would not accurately predict the actual dynamic load. Callaghan *et al.* (2001) indicated that 'average error with this approach may be high' Nevertheless, Callaghan believes that 'using reduced data approaches like this one are necessary and the only practical way to assess real industrial data, as this paper explores' (Personal Communication). Callaghan *et al.* (2003) suggested that a 3 Hz sampling rate for posture would be as good as a 60 Hz sampling rate. However, because the sampling would all be static, neither of these approaches would necessarily provide an accurate estimate of the dynamic load. Thus, we opted to use the single static spinal load values at the lift-off point,

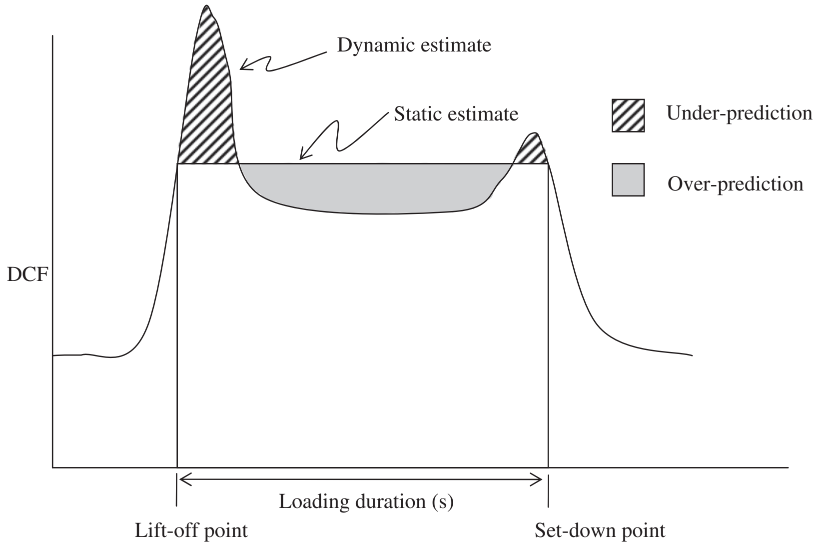

Figure 3. Theroetical cumulative dynamic load vs. cumulative static load (DCF: Disc compression force).

since this would likely be the peak load throughout the lift. We recognise that the dynamic curve is dependent upon many factors and may not be as simplistic as that demonstrated in Figure 3. Additionally, we recognise that the validity of this assumption remains to be determined, especially across a wide range of task conditions. This data reduction approach for cumulative load has been used in the past to examine spinal loading in epidemiological studies of back pain (Norman *et al.* 1998).

### 2.5.2. *RNLE calculations*

The primary RNLE outcome variables of interest were the NIOSH Recommended Weight Limit (RWL) and the LI or Composite Lifting Index (CLI) for each job. CLI or LI can be calculated based on the four RNLE parameters ($H$, $V$, $D$ and $A$) and lifting frequency, which are obtained from the human posture simulation method, as well as the remaining RNLE parameters, which are entered manually, which include the work-rest hour duration category (i.e. 1, 2 or 8 h), coupling factor (good, fair or poor) and whether significant control is required or not. The RNLE outcome variables could then be used to assess the risk of LBDs.

## 3. Discussion and limitations

Many of the previous methods used to calculate CSL are time consuming and do not provide an accurate estimate of the working postures over time (Waters *et al.* 2006). For the method described in this article, however, working postures are obtained via human simulation of videotaped sessions of workers performing the job. The accuracy and precision of the human posture simulation is described subsequently in our Part II paper (Lu *et al.* 2010). For the proposed method, we chose to use 3DSSPP software to calculate the various spinal loading parameters for each individual lift. This approach is based purely on a static measure of posture and does not allow the inclusion of dynamic factors or muscle coactivity. As noted earlier, our assumption was that the over- and under-prediction resulting from using the approach we selected would likely yield a reliable cumulative load estimate. The proposed procedure can be applied to any manual material handling job, including pushing, pulling and lifting, but it is especially applicable to jobs in which workers rotate between work stations or perform jobs with highly variable task characteristics. It will also apply across a wide range of industries, including manufacturing, agriculture, maritime, mining and warehousing.

Regarding the method of integrating the biomechanical load over time, we simply calculated a cumulative load estimate for each lift and then simply added the individual components together over a fixed period of time to get the overall CSL parameters for that time period. Other approaches, such as weighting various components of the loading (e.g. weighting specific lifts or postural loads), and/or weighting loading over time could also be possible with the data acquired using the proposed CSL analysis method.

As discussed in Section 1, jobs with rotation schemes are difficult to assess. The proposed method would work well for jobs with rotation schemes due to its ability to include risk variations associated with all jobs in a job rotation scheme. Job rotation has become an important work method that is popular in many industries. Several studies have indicated production and personnel-related benefits of job rotation (Farrant 1987, Hazzard *et al.* 1992, Cheraskin and Chapion 1996, Gittleman *et al.* 1998, Cosgel and Miceli 1999, Kuijer *et al.* 1999, Davis and Jorgensen 2005, Eriksson and Ortega 2006). A job in which the worker rotates between multiple lifting tasks during the shift is difficult to assess with the RNLE and other traditional assessment methods. Waters *et al.* (2007) recently proposed the Sequential Lifting Index (SLI), a method for assessing manual lifting jobs that are performed in a rotation scheme. While the SLI method proposed by Waters *et al.* (2007) would be better for assessing lifting jobs with rotation schemes than previously available, the SLI would still not be sensitive to differences in the total physical exposures over the course of the shift for the three jobs shown in Figure 3, and also would result in the same SLI value for each job. Therefore, it is likely that there would be significant benefit from using a CSL method to assess manual lifting tasks that are performed in a rotation scheme over the course of a work shift.

A significant limitation of this method is that it does not allow simulation or estimation of the dynamic loads, but rather relies on a static video image. The only valid way to account for dynamic loading is to actually measure the variables during performance of the task, which is primarily limited to laboratory assessments. Also, the proposed method does not allow for coactivity of the spinal muscles, which has been shown to significantly affect the spinal DCF and SF estimates for many manual material handling tasks (Marras 2008). Another limitation of the proposed approach is that a trained simulator of matching height is required for the simulation. Also, we did not match the simulator to the observed worker for gender and age, which could result in some error. Future studies may want to examine the issue of simulator matching on anthropometry.

Although a wide range of methods have been used to capture postural data, few are capable of capturing the dynamic movements of workers in field environments. One option is to simulate the jobs in the laboratory, but this is difficult for epidemiological studies in which many jobs with numerous job rotation schemes are involved. These limitations in our ability to actually capture the dynamic aspects of the loading likely result in an underestimation of the actual magnitude of the CSL which would lead to an underestimation of the magnitude of association between CSL and development of low back pain. It also should be noted that this method involves a simulation rather than actually measurement of task variables in the field. Nevertheless, we have shown that the method is a reasonable approach to assessing real world jobs.

In summary, the CSL method likely is more sensitive to the overall physical demands of manual lifting tasks that are not performed continuously for a work shift than most existing assessment methods. It remains to be seen, however, whether the current CSL method is a valid predictor of risk of LBDs and whether the assumptions upon which the method are based are correct.

## Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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