Measurement and Evaluation of Physical Load at the Workplace

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Summary

The measurement and evaluation of the physical load on the musculoskeletal system at the workplace is a fundamental component of efforts to prevent work-related musculoskeletal disorders. There are numerous methods available, ranging from more qualitative self reports to quantitative direct measurements using instrumentation. Several tools for analyzing the potential for low-back and upper extremity musculoskeletal disorders are described. The practical tradeoffs between the methods are delineated.

Samenvatting

Het meten en evalueren van fysieke belasting op de werkplek is een fundamenteel onderdeel van inspanningen om werkgerelateerde aandoeningen aan het houdings- en bewegingsapparaat te voorkomen. Er bestaan vele methoden, variërend van min of meer kwalitatieve zelfrapportage tot kwantitatieve directe metingen met behulp van meetinstrumenten. In dit artikel wordt een aantal methoden voor het analyseren van risicovolle blootstelling voor de lage rug en de bovenste extremiteiten beschreven, alsmede de voor- en nadelen van de deze methoden.

Introduction

A key step in the primary prevention of work-related musculoskeletal disorders (WMSDs) is the measurement and evaluation of physical loading on the musculoskeletal system. As part of a systemic approach to the prevention of WMSDs, measurement and evaluation of physical loading provides valuable information for job design and redesign decisions. However, it is important to view measurement and evaluation from the perspective of broader efforts to prevent work-related injuries and illnesses. Typically, the occurrence of discomfort, pain, and/or musculoskeletal disorders prompts an investigation. The measurement and evaluation of physical loading plays a key role in identifying stressful job components so that solutions can be developed and implemented.

The loss prevention process, which is usually ongoing, should include the following:

1. Surveillance - Active and passive surveillance activities identify potential problems and existing problems, respectively. Active surveillance includes worker surveys to solicit information on discomfort, pain, or symptoms related to the work tasks. Passive surveillance involves analyzing previous injuries and illnesses to determine the job, department, task, etc., associated with losses.
2. Measurement and Evaluation of Physical Loading - A key step in the loss prevention process is evaluating those aspects of tasks, machines, equipment, and work organization that may lead to losses. This step is discussed in more detail below.
3. Alternative Solutions Development - Once the problems are identified, it is beneficial to develop alternative solutions. The selection of the solution will depend on, among other factors, technical and economic constraints. Similarly, the evaluation method used to analyze the job can provide relative estimates of the efficacy of the solution. For example, when a biomechanical approach is used, the analyst can express the percentage reduction in spinal compression the different solutions will offer.
4. Solution Implementation - Once a solution is selected, the next step is to implement the solution. This may be a discrete implementation or a continuous improvement effort carried out over time.
5. Continued Surveillance - Following implementation, Step 1 should be continued to determine if further redesign is required (and Steps 2-5 if problem continues).

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Selection of Measurement and Evaluation

A challenging aspect of workplace assessment is the selection of the particular method that will be used. Figure 1 presents a brief summary of the types of methods available, ranging from self reports by workers, direct observation, to direct measurement. Direct measurement often involves instrumentation attached to workers' bodies (such as electromyography electrodes to measure muscle activity and electrogoniometers to measure joint motion), whereas direct observation involves measurements taken by the analyst. The types of measurements include dimensions such as conveyor heights and distances loads are carried, load weights, etc. Self reports are surveys, etc., performed by workers. Progressing from self report to direct measurement, the cost, time, and expertise required usually increase, and often the amount and quality of information increase. For example, well-designed instrumentation can often provide more accurate and precise data on joint motion (quality), as well as provide a continuous recording (quantity) when compared to questionnaire or observation data. However, the trends do not follow this pattern in a few cases. For example, an interview can provide as much or more information as direct measurement. The discussions to follow will focus more strongly on direct observation.

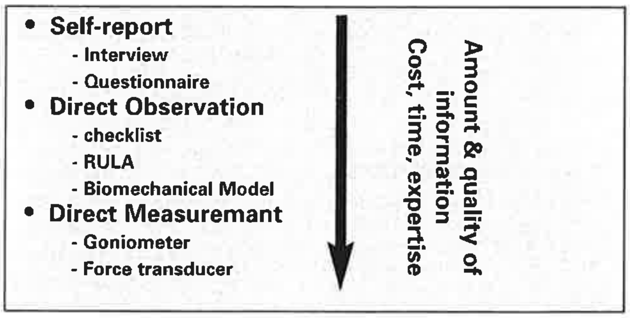

Figure 1. Overview of tradeoffs when selecting a measurement and evaluation method.

Measurement and Evaluation of Physical Loading on the Low-Back

Physical loading on the back is often assessed using different design criteria such as spinal compression (biomechanics), oxygen consumption (physiology), and the percentage of the population that finds a task acceptable with respect to fatigue and stress (psychophysics). Although these criteria are assumed to prevent low-back disorders, epidemiological evidence is sparse. However, these criteria have substantial application to job design, which is rarely differentiated from risk assessment.

Major Assessment Methods

Manual handling criteria are applied through observational methods. The analyst first separates a job into distinct tasks, and then the parameters of the tasks are measured. The methods discussed focus on those that can be accomplished through the use of a tape measure, protractor and watch. The parameters measured include joint angles, task frequency, lift distance, and object weight. The practical aspects of selecting a method, such as expertise and cost, are shown in Table 1. The use of a biomechanical model usually requires purchasing a model. These models are applicable to tasks requiring high forces or handing heavy loads, and provide a relative assessment of different job components (e.g., task 3 causes the highest spinal compression). However, these static models ignore the effects of motion and should be used by those with knowledge of statics and dynamics. Psychophysical tables are among the easiest methods to use and cover the broadest range of tasks (see Snook and Ciriello (1991) or Mital et al. (1997) for tables). Some argue that these data ignore high physiological and biomechanical demands. Energy expenditure models are helpful for assessing the fatigue potential of high frequency tasks, but most models are based on rather limited samples of college students.

Risk Assessment versus Compliance Assessment

The results of a manual materials handling (MMH) evaluation should be interpreted in the proper context. Although the measurement of physical load due to MMH is often expressed quantitatively, the evaluation of the load is often assumed to represent a risk assessment. For instance, users of the NIOSH equation almost always assume that the risk of low-back disorders becomes unacceptable when the lifting index exceeds 1.0. However, the epidemiological data to support this type of use do not exist. While most would agree that a task with a lifting index of 3.0 is likely to pose more risk than a task with a lifting index of 1.0, there is little consensus regarding the actual lifting index that should be considered a 'threshold'. Rather than considering the evaluation a risk assessment, it may be more appropriate to use the term 'compliance assessment' for the reasons discussed below.

Risk assessment is a process comprised of several components. The National Research Council (1983) has defined these components as: (a) hazard identification, (b) dose-response assessment, (c) exposure assessment, and (d) risk characterization. As the National Research Council (NRC) pointed out, not every risk assessment will consist of all components.

A true risk assessment is rarely possible when MMH criteria are used, as there are few, if any, dose-response relationships between criterion values and injury cost or severity. The dose-response relationship is typically replaced by predictions of the acute responses of the cardiovascular and musculoskeletal systems to a particular task design. These responses are assumed to approximate risk; however, there is not strong epidemiological support for this assumption (e.g., Dempsey, 1998). The term compliance assessment denotes the process of analyzing MMH tasks when dose-response relationships are replaced by comparisons of observed criterion values to a

Assessment Method	Major Advantages	Major Disadvantages
Biomechanical Model	1. Appropriate for jobs requiring high forces, handling of heavy loads 2. Quantitative 3. Covers lifting, lowering, pushing and pulling	1. Practicality limits application to static analyses in the workplace - this may under-estimate stress and limits scope of job that can be analyzed 2. Fairly expensive (if software is purchased) 3. Fairly high expertise required 4. Carrying is excluded
Psychophysical Tables	1. Easy to use 2. Inexpensive 3. Covers lifting, lowering, pushing, pulling and carrying 4. Extensive data available 5. Can be used for non-standard MMH tasks (e.g., mining)	1. May ignore high biomechanical and physiological demands 2. Based on subjective responses
Energy Expenditure Models	1. Appropriate for high frequency tasks 2. Usually the only practical method of assessing energy expenditure	1. Validity of available models is questionable (i.e., large errors are possible) 2. Relationship between energy expenditure and health effects has not been demonstrated
1991 NIOSH Equation	1. Captures major risk factors associated with lifting and lowering 2. Is a useful tool for training non-ergonomists on how different parameters affect lifting capacity	1. Has not been validated 2. Applies to few MMH jobs 3. Only applies to lifting and lowering

Table 1. Overview of major MMH assessment methods.

specific MMH criterion. Within the context of industrial hygiene, Claycamp (1996) defined compliance assessment as 'compar[ing] predicted/measured exposures with relevant standards or occupational exposure limits.' Analyses using MMH criteria can be considered compliance assessments rather than risk assessments (Dempsey, 1999).

Evaluating Jobs versus Tasks
Although most manual handling exposures are far more complex than performance of a single MMH task, methodologies for analyzing multiple-task MMH jobs are limited to very few options. Most approaches to MMH task analysis focus on specific types of MMH tasks such as lifting, although a few are appropriate for analyzing a broader spectrum of MMH tasks. When analyzing jobs, often the best approach is to analyze tasks and use the results to identify tasks that cause the highest stress. This can be particularly valuable when not all tasks can be redesigned at once.

Measurement Error
A study was conducted to evaluate the accuracy of users' measurements of lifting and lowering task parameters when using the revised NIOSH equation (Dempsey et al., 2000). The following conclusions were made:

1. Users of the NIOSH equation should receive formal training.
2. The length of training and/or the complexity of the tasks measured can affect users' ability to measure parameters.
3. Due to the sensitivity of the lifting index (LI) to errors in frequency and horizontal location measurements, these parameters should receive priority when providing training. Additionally, these parameters are rather difficult to measure compared to the vertical locations (and hence distance traveled). For instance, a sensitivity analysis demonstrated that errors in frequency could result in an LI between less than 1.0 to over 6.0. In practice, this indicates that the results of the analysis could lead to incorrect decisions regarding whether or not a task needs to be redesigned.

Measurement and Evaluation of Physical Loading on the Upper Extremity

Choices for measuring and evaluating physical loading on the upper extremity are more limited than for low-back assessment. Measurement and evaluation is accomplished through observational techniques designed to measure force, posture, and repetition. Direct measurement is required to measure exposure to hand-arm vibration, and equipment is available to measure force and posture. Unfortunately, devices for direct measurement of force and posture are often prohibitively expensive. For example, electrogoniometers to measure wrist deviation are quite expensive and require considerable technical expertise to operate. A brief overview of task analysis techniques for performing an elemental analysis of a job will be given.

Checklists
Checklists are useful for performing an initial assessment of jobs. Although checklists do not provide a job analysis, they help identify those tasks or task elements that should be analyzed in more detail. Several checklists exist, and one choice is the 'Michigan Checklist' developed by Lifshitz and Armstrong (1986) (see also Putz-Anderson, 1988). The checklist will indicate those aspects of a job or task that should be analyzed in more detail. In the U.S., the State of Washington Department of Labor and Industries has recently developed an ergonomics rule proposal. It contains, among other analyses, what is essentially a checklist for preventing WMSDs of different body parts. For example, repetitively pinching objects weighing more than two pounds (0.9 kg) for more than 3 hours/day would indicate a hazard that has to be abated or reduced. Numerous risk factors are included in this approach.

Observational Techniques
The Rapid Upper Limb Assessment (RULA) method of analyzing upper extremity tasks (McAtamney and Corlett, 1993) is an efficient, cost effective method for identifying problematic task elements. This technique is applied by observing and categorically rating forearm rotation, and the posture of the upper and lower arms, the wrist, the neck, and the trunk. The balance and support of the legs are rated, and the forces or loads handled (load score) are rated. Whether or not postures are static or repetitive (muscle use score) are also considered. These ratings are used to determine an upper limb posture score and a neck, trunk, and legs posture score (through tables). Posture scores are then used with load and muscle use scores to arrive at a 'Grand Score' between 1 and 7. The analyst can then assess the task or compare the relative stresses posed by different tasks within a job.

Conclusions

It is important that the assessment method chosen is appropriate for the question being answered. For example, checklists are designed to identify problematic elements of tasks and jobs, not to provide an assessment. Similarly, they often do not answer specifically what is 'bad' about a job at the level of detail required to guide redesign. The same is true of active and passive surveillance methods. If a job is known to be hazardous and requires redesign, more detailed information available from direct observation or measurement techniques are often needed. These more detailed data are particularly useful when selecting and justifying recommended changes.

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