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ERGOWATCH: A NEW MANUAL HANDLING MANAGEMENT TOOL

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Introduction

Lower back pain (LBP) due to manual handling (MH) imposes a considerable financial and social cost on the community (Worksafe Australia, 1993; Nachemson, 1992). For example in 1994-95 workers compensation claims in Australia cost $4.1 billion (Worksafe Australia, 1996), with back injuries accounting for 28% of these claims, 69% of which were caused by over exertion during lifting (Worksafe Australia, 1995).

One approach to LBP prevention involves the study of the forces acting on the spine during MH. The main assumption underlying this approach is that the risk of injury to the low back associated with MH is causally related to spinal loading (McGill, 1997). According to this approach, if spinal loads associated with MH can be accurately determined, then potentially dangerous MH tasks can be identified and risk control strategies implemented.

The first comprehensive and commercially available software package for estimating the spinal loads associated with MH tasks was the three-dimensional static strength prediction program (3DSSPP, University of Michigan, 1993). 3DSSPP is a static biomechanical model that computes compression and shear forces at the lumbosacral (L5/S1) joint from input describing the orientation of the segments of the body and the magnitude and direction of the hand load. Estimates of L5/S1 compression force can be compared with prescribed safe lifting limits to ascertain the degree of low back injury risk associated with specific MH tasks. Stevenson (1998) previously published a review of 3DSSPP in this journal. In the current paper we review a new software package for managing MH developed at the University of Waterloo, known as Ergowatch.

The purpose of this review is to: (i) describe the main features of Ergowatch, with particular emphasis on the part of Ergowatch known as 4D Watbak, which is a biomechanical modelling tool concerned with estimating and evaluating spinal loads; and (ii), to provide an example of how Ergowatch can be applied to the analysis of a 'real world' MH task. Specific attention will be paid to the theoretical basis of Watbak, including a discussion of its main assumptions and limitations.

Description of Ergowatch

Ergowatch is a four-part software program based on the latest scientific research that was specifically designed for use by Occupational Health and Safety practitioners. Ergowatch consists of 4D Watbak, NIOSH Tool, Snook Tool and PDD Checklist programs and operates on the Windows 95 platform. The version reviewed here is Ergowatch Beta Version 1.1, which was released for review in 1999. It is expected that Ergowatch will be officially released early in 2000.

4D Watbak

4D Watbak is a biomechanical modelling program that estimates the loads acting at the junction between the 4^{th} and 5^{th} lumbar vertebrae as a function of body segment angles, lumbar spinal curvature and the magnitude and direction of the hand load. The four dimensions of Watbak are the three dimensions of space and one of time. The time dimension is incorporated to estimate the cumulative loads acting on the spine during tasks performed over a full working day. The beta version of Watbak reviewed in this article is restricted to the sagittal plane, however the full three-dimensional version of Watbak is expected to be released in the year 2000 as a program upgrade.

NIOSH Tool

The NIOSH Tool implements the National Institute of Occupational Safety and Health (NIOSH) manual handling equations (NIOSH, 1981; 1991) to estimate acceptable and maximum weight limits for specific MH tasks, which can then be compared to the actual weight lifted. Weight limits are calculated by the 1981 equation from horizontal and vertical position of the load, vertical displacement of the load, lifting duration and frequency parameters. The 1991 equation uses the same parameters as the 1981 model as well as a qualitative assessment of the coupling of the hand to the load and the degree of twisting in the MH task.

Snook Tool

Based on psychophysical research by Snook (1978) and Snook and Ciriello (1991), the Snook Tool predicts the maximum acceptable weight of a specific MH task (MAWL) for certain percentages of the population. Lifting, lowering, pulling, pushing and carrying tasks can be analysed by the Snook tool, based on input describing gender, object dimensions, the distance the object is moved and the frequency of the lift. The output indicates the maximum weight that is physiologically acceptable for specific percentiles (90, 75, 50, 25 & 10%) of the population. According to Snook et al. (1978), workers who lift loads that are acceptable to less than 75% of the population are three times more likely to develop LBP.

Physical Demands Description Checklist (PDDC)

PDDC contains the Functional Capacity Evaluation (FCE) and the Physical Demands Description (PDD) questionnaires, which have been adapted from the 1980 Ontario Ministry of Labour, Physical Demands Analysis form. FCE and PDD questionnaires are designed to identify risks in the workplace and provide an indication of the ability of an employee to perform a MH task safely. The assessment provided by these questionnaires is based on strength, mobility, sensory/perceptual, work environment and conditions of work.

Description of the 4D Watbak Spinal Modelling Program

In this section a brief account of the theoretical basis of Watbak is provided, followed by a description of the Watbak User Interface, and a discussion of the main assumptions and limitations of Watbak.

Theory

The current 2D beta version of Watbak represents each subject using 14 body segments (ie. 2 × hand, 2 × forearms, 2 × upper-arm, head, trunk, 2 × thigh, 2 × shank and 2 × foot segments). Mass, length and centre of mass (COM) of each body segment are estimated from the subject's height and weight, based on the equations developed by Plagenhoef (1971), Dreyfuss (1966) and Zatsiorsky and Seluyanov (1983). Spinal loads are calculated via Newtonian equations that sequentially calculate the reaction forces of each joint of the upper body starting at the hands. Reaction forces in the joints of the lower extremities are calculated starting at the ground reaction force (GRF) applied to the foot segments. The resultant GRF is estimated via vector addition of the subject's body weight and the hand load vector.

L4/L5 compression forces are estimated from the sum of the reaction force normal to the vertebral end plate and the compression force due to the lumbar musculature. Normal reaction forces and moments at L4/L5 are calculated via static equations of motion. The compression force due to the lumbar musculature is calculated from the moment generated at L4/L5, assuming a single equivalent muscle model with an extensor moment arm of 6 cm (Potvin et al., 1991; McGill et al., 1986). If the moment about L4/L5 is a flexion moment, a single equivalent abdominal muscle force with a moment arm of 4.5 cm is assumed (McGill, 1996).

Watbak calculates two types of shear force, reaction shear and joint shear. Reaction shear is calculated from the sum of the hand load and upper body weight forces acting parallel to the vertebral end plate, whilst the joint shear force also incorporates the effect of forces exerted by the lumbar muscles and ligaments. McGill and Norman (1987) and MacIntosh and Bogduk (1987) reported that the lumbar extensor musculature is aligned oblique to the lumbar spine when the lumbar lordosis is maintained, and is aligned parallel to the vertebral column at L4/L5 during full flexion. Therefore, Watbak incorporates a posterior shear force from the lumbar extensors during lordosis and no shear force during lumbar flexion. Although Watbak assumes that no posterior shear force is produced by the lumbar extensors when the lumbar spine is flexed, the model does incorporate the anterior shear force generated by the obliquely aligned spinal ligaments (McGill, 1988). Ligament forces in both the lordotic and fully flexed postures are estimated based on a moment arm of 6 cm (Potvin et al., 1991). Joint shear force is subsequently calculated by adding any anterior shear force produced by the ligaments to the reaction shear force and subtracting any posterior shear force generated by the lumbar extensors. Watbak defines anterior shear force as positive and posterior shear force as negative.

To aid the user when interpreting the spinal compression and shear forces estimated by Watbak, these forces can be compared to lumbar spinal force limits reported in the literature. L4/L5 spinal compression limits incorporated into Watbak include; (1) the NIOSH Action Limit (AL) and Maximum Permissible Limit (MPL) (NIOSH, 1981), (2) the age and gender related limits set by Jager et al. (1991), and (3) the population specific limits recommended by Genaidy et al. (1993). According to NIOSH (1981), L4/L5 compression forces above the AL (3433 N) are considered potentially hazardous for some workers and require ergonomic or administrative intervention, whilst L4/L5 spinal forces above the MPL (6376 N) are considered hazardous to most workers and immediate task modification is recommended. In 1991 the NIOSH equation was modified to give the Recommended Weight Limit (RWL) and Lifting Index (LI). The RWL assigns a weight that nearly all healthy individuals could lift over a full eight-hour shift without a significantly increasing the risk of developing LBP. The LI is calculated by dividing the weight lifted during the MH task by the RWL. A LI greater than 1.0 poses an increased risk of LBP for some individuals, whilst a value over 3.0 indicates an increased risk of LBP for a substantial fraction of the workforce. The 1981 and 1991 spinal compression limits set by NIOSH are neither age or gender specific.

Compared to limits for spinal compression, less attention has been paid to the development of spinal shear force limits. Watbak includes University of Waterloo Action Limit (UW AL) and University of Waterloo Maximum Permissible Limit (UW MPL) lumbar shear force thresholds, based on research by McGill et al. (1998). Shear UW limits are only appropriate for anterior shear experienced at L4/L5. No posterior shear force limits have been set. Anterior L4/L5 shear limits in Watbak are gender specific and have been set at 500 N (UW AL) and 1000 N (UW MPL) for men and 330 N (UW AL) and 660 N (UW MPL) for women.

Cumulative spinal forces and torques are calculated by multiplying the joint load by the duration of the task and are reported as cumulative forces or torques (N.s or Nm.s) per task or per shift. Because the *peak* spinal force is multiplied by time the cumulative force is likely to be over predicted by Watbak.

Finally Watbak uses statistical odds ratios to generate LBP Index estimates (from 0-1) from peak and cumulative forces. The LBP Index is designed to indicate the level of risk for acute and cumulative load based on research by Norman et al. (1998), which used a regression analysis to predict LBP ‘cases’, as a function of lumbar spine moment, L4/L5 compression force, L4/L5 shear force and the force experienced at the hand.

Watbak User Interface

Watbak presents input entry points and output data in a dual panel format. The left panel has five tabs (Info, Job, Posture, Force & Output) whilst the right panel displays a mannequin representation of the task being analysed. An example of the user interface for a worker lifting a car tyre from the ground is presented in Figure 1.

Height, weight, gender and age of the worker must be specified in the ‘Info’ tab before Watbak can generate any output data. Subject and analyst details can also be recorded in the ‘Info’ tab, along with any explanatory notes.

Before Watbak provides a mannequin representation of the worker in the right panel an action needs to be added to the task list in the ‘Job’ tab. The number of repetitions and the duration of MH tasks under analysis are defined in the ‘Job’ tab so that Watbak can calculate cumulative load estimates. To analyse a single task only one action needs to be defined, however Watbak is also able to group and analyse many different MH tasks performed by an employee. Grouping tasks can be particularly useful in identifying risky MH practices amongst the many tasks performed throughout a working day.

Symmetrical and asymmetrical postures can be created in the 'Posture' tab by adjusting the individual body segment angles, with an accuracy of up to $1/100^{th}$ of a degree. Alternatively the posture can be manipulated by 'clicking & dragging' individual segments of the mannequin in the right panel, with corresponding joint angles simultaneously displayed in the 'Posture' tab. By default Watbak limits the range of motion (ROM) of each body segment, including the lordosis of the lower back, based on functional anatomical ROM research conducted by Magee (1987). The lumbar spine switches automatically to a flexed posture once the hip angle is greater than 80 degrees, however, both the ROM limitations and automatic lumbar flexion can be overridden if required.

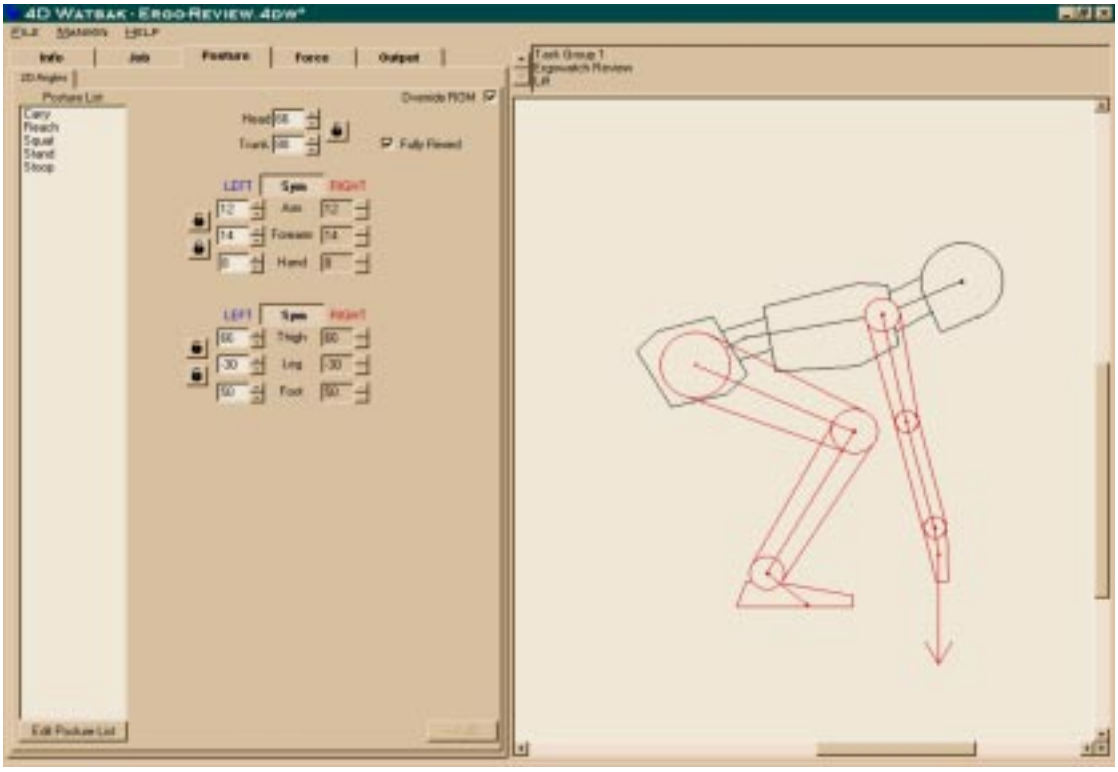
The magnitude, direction and distribution of the external load in each hand can be manipulated in the 'Force' tab. As the hand load is manipulated its vector representation on the mannequin and the corresponding change in spinal load estimates are simultaneously updated by Watbak.

Watbak calculates an array of acute and cumulative force estimates from anthropometric, posture and hand force inputs, which are presented in a variety of tabulated and graphical forms in the 'Output' tab. One of the most useful graphical representations of acute L4/L5 compression and joint shear force displays the lumbar forces as bar graphs (eg. figure 1b). A choice of three types of lumbar compression limits (NIOSH, Jager or Genaidy) can be superimposed upon the graph to compare with the calculated compression loads. Likewise gender specific University of Waterloo shear force limits are superimposed on the joint shear bar graph to aid in evaluation of the lumbar shear loads, but only when Watbak calculates an anterior shear force at L4/L5, as posterior shear force limits have yet to be determined.

Although there are no limits for cumulative loads where injury becomes more likely, estimated cumulative forces are useful when comparing the risk associated with various MH tasks. Cumulative and acute loads during unaccounted time (ie. periods during a shift where no task is analysed) are calculated assuming a standing posture with the trunk flexed 5 degrees. Cumulative loads are presented in units of N.s or Nm.s.

LBP Index ratios based on epidemiological research by Norman et al. (1998) are also reported in the 'Output' tab. LBP Indexes (ranging between 0 and 1) can be used to gauge the LBP risk associated with particular MH tasks. (Eg. A LBP index of 0.67 represents a 67% chance of reporting LBP).

(a)



(b)

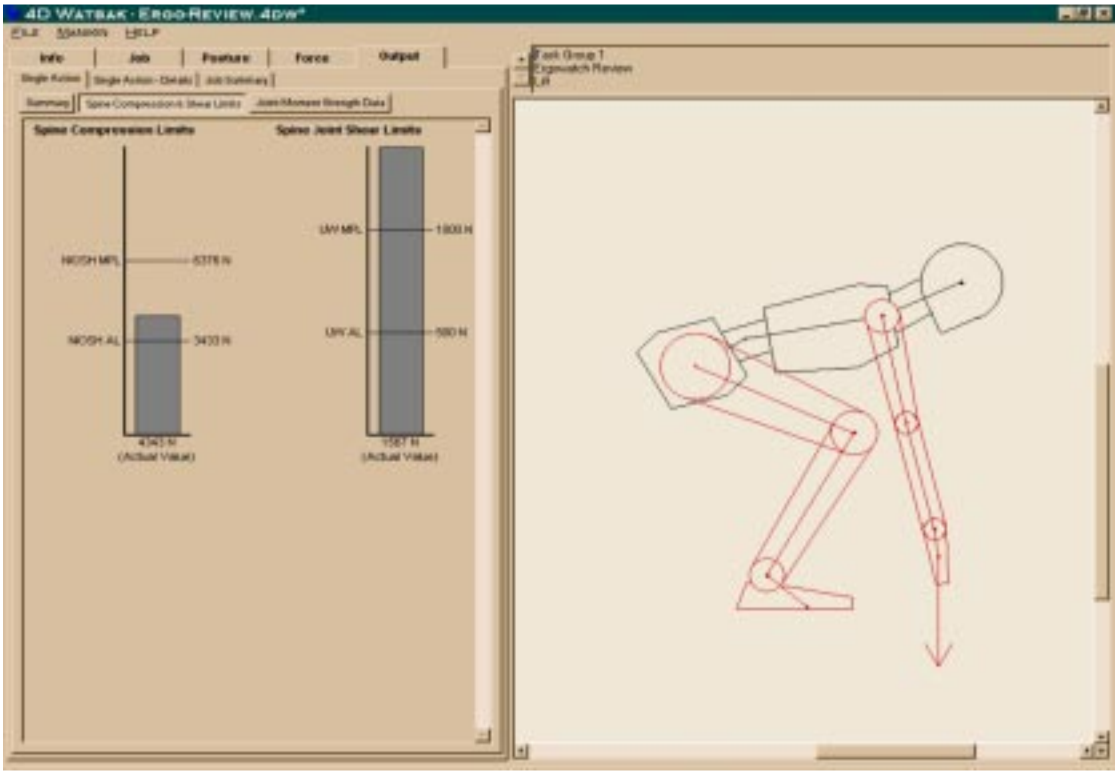


Figure 1. Watbak dual panel user interface showing (a) the posture tab and (b) the output tab on the left panel, together with the mannequin representation of the worker on the right panel. The bar graphs in the output tab represents the magnitude of the spinal compression and shear force estimates by Watbak, and are shown relative to the NIOSH compression force and University of Waterloo shear force limits