Prevention of low back pain: basic ergonomics in the workplace and the clinic

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Nachman Halpern
New York University

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Prevention of low back pain: basic ergonomics in the workplace and the clinic

M. HALPERN

Musculoskeletal injuries, both acute and chronic, can be understood as a component of the overall medical classification, disorder. Descriptive examples of the term injury include sprains, strains, inflammations, irritations and dislocations. In contrast, accidents resulting in injuries in which the skin or bones are broken are defined as traumatic injuries. Injury resulting from exposure to continued trauma is often defined according to the structure thought to be inflamed, irritated or strained, for example, nerve entrapment or lumbar pain (NIOSH, 1986).

There is a growing awareness among administrators, practitioners and researchers that musculoskeletal injuries are often activity related. Much of this activity occurs at the workplace. It is reasonable to hypothesize that work-related factors can cause musculoskeletal disorders, aggravate their condition and impede rehabilitation. Conversely, modification of work-related factors can prevent the disorders and assist in returning patients to work. Every health care provider (HCP) sees patients who are suffering from work-related conditions. But how often are the patient's symptoms treated independently from their occupational aetiology? The effective medical management of work-related musculoskeletal disorders starts at the case history. The clinician must assess the importance of various factors in the aetiology of the patient's condition so as to appraise the extent to which they are under the control of the patient. It is pointless to instruct someone to bend the knees, not the back, while lifting, if the physical constraints of the work situation would prevent this. Job familiarity is one key to an effective medical management of occupational disorders. Recognizing the connection between possible risk factors and the patient's clinical condition is part of good medical practice. But successful management of occupational disorders goes beyond medical management. The HCP should be familiar with the efforts made in other areas to control work-related medical problems. These efforts may not involve the HCP but they certainly affect the patients and the success of the treatment and rehabilitation. It is proposed that a common conceptual framework of intervention strategies would improve the communication between all the parties involved in prevention of musculoskeletal injuries, including low back pain.

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Three main approaches are currently used for intervention in jobs in which the physical demands pose a risk to the musculoskeletal system:

1. Redesign the job or tool to fit the worker.
2. Train workers in techniques to reduce job hazard.
3. Select only those individuals whose work capabilities meet or exceed the job demands.

The first approach has been a basic tenet of occupational safety and health practice, in preference to training or selection.

The practice of fitting the job to the worker is called 'ergonomics'. Literally, 'The natural laws of work', ergonomics is the study of human capabilities with respect to job demands. Ergonomists study human behaviour at work. To study human behaviour at work we need to apply knowledge from numerous disciplines, most notably engineering, biomechanics, physiology and psychology. The ergonomist faces the challenge of integrating this knowledge.

Ergonomic modifications in machine and environmental design can be generally applied to all employees. The goal is to adapt the machines and the environment to the largest percentage of the population. In this case it can be classified as 'primary prevention'—the effort to prevent the initiation of a disorder. However, similar techniques and solutions can be used to accommodate employees with specific needs. This makes ergonomic knowledge relevant also in rehabilitation, or in 'secondary' and 'tertiary prevention'. The former is the effort to detect the disorder in a preclinical stage and modify its progress. The latter is the effort to minimize the consequences of a disorder, e.g. through accommodation to the individual patient. When applied to low back pain (LBP) these categories tend to overlap (Andersson, 1991a). In an effective medical management programme, the HCP ideally should be involved in all stages of prevention.

Prospects for reducing work-related musculoskeletal disorders depend on progress in four methodological areas (NIOSH, 1986):

1. Identifying the biomechanical hazard.
2. Developing effective health-control interventions.
3. Changing management concepts and operational policies with respect to work performance.
4. Devising strategies for disseminating knowledge on control.

This chapter discusses the progress in these four areas as they pertain to redesigning the job and the tools, i.e. to ergonomics. It addresses separately the application of ergonomics in primary and secondary or tertiary prevention programmes of low back pain or injury. The terms *pain* and *injury* are used interchangeably. From an ergonomic viewpoint, low back pain is synonymous with injury; both reduce the capability of the worker, they require similar approaches to evaluate their risk, and need similar solutions to control them.

OCCUPATIONAL RISK FACTORS

To redesign work to reduce the risk of musculoskeletal injury, we need to know the capabilities of the human operator and the demands of the job. Knowing what demands are hazardous is the first step towards modifying the job.

Much of what is known about the risk factors for low back injury is based on epidemiological data (see Chapter 2). Two categories of factors that modify the risk of injury have been differentiated from various surveillance efforts: factors associated with the job and personal factors. Job tasks determine the physical effort at work. Personal factors determine the physical capabilities of the workers. A review of the epidemiological studies on risk factors of LBP lists 24 work-related factors and 55 individual factors which may be regarded as risk indicators (Hilbrandt, 1987).

The relationship between the physical effort required on the job and back injuries is not well defined. Several methodological problems complicate the research in this area. First, physical effort is a construct of several components such as strength, flexibility or stamina. It follows that an investigation of physical effort requires a multifactorial research design. Second, these components do not have a standard definition. This makes a comparison between studies difficult. Third, each component has several dimensions: the amount, frequency and duration of exertion are necessary to evaluate the magnitude of physical effort. Consequently, investigations in this area require several types of measurements which are difficult to perform in the workplace.

Physical effort is only one of the occupational risk factors that the employee is exposed to at work. Adverse work conditions and unsafe practices also contribute to occupational musculoskeletal injuries. Work conditions and worker practices interact with physical effort. For example, the effects of environmental factors such as heat are well known; the impact of psychosocial factors on physical effort is more difficult to assess.

It is not surprising that only few studies have been designed to investigate multifactorial exposure at work. Despite the methodological problems, several job demands related to physical effort have been associated with back injuries. These have been classified as follows (Hilbrandt, 1987; Andersson, 1991b):

General
– heavy physical work
Static work-load
– sustained trunk posture (stooping, reaching)
– prolonged sitting
Dynamic work-load
– frequent bending and twisting of the trunk
– lifting, lowering, pushing and pulling activities
Environmental factors
– exposure to whole-body vibration

Epidemiological data indicate that three kinds of risks are involved with these job demands:

1. The risk of accidental or traumatic injury, due to slips and falls, etc.
2. The risk of overexertion or acute injury.
3. The risk of cumulative damage.

Although it may not be possible to separate these risks in any particular case, general guidelines may still be conceptually useful. Accidents and overexertion injuries are dynamic in nature. Cumulative damage is probably a result of both static and dynamic loads. Back injuries are predominantly classified as overexertion. Although manual material handling activities such as lifting, carrying or throwing are recorded in nearly 70% of the overexertion injuries, we cannot conclude that manual material handling poses a risk mainly to the trunk: the upper limbs and lower limbs seem to be equally involved in handling accidents (Pheasant, 1991).

Once we identify which job demands are associated with back injuries, we then need to evaluate the magnitude fo these factors. The magnitude, such as the weight lifted, is important, especially concerning the actual and perceived capacities of the individual (Bigos and Battié, 1991).

EVALUATION AND DOCUMENTATION OF PHYSICAL JOB DEMANDS

Three approaches have been used to determine the magnitude of physical job demands that are associated with LBP. These are the biomechanical, physiological and psychophysical approaches.

The biomechanical approach

Studies using this approach attempt to find physical attributes of the individual and the job that may be potentially damaging to the musculoskeletal system. The load held by the hands and the weight of the limbs create rotational moments or torques around the body joints involved. Muscles are positioned so that they counteract the torques through short moment arms and produce large motions of body segments with small changes in muscle length. The torques are created not only in the joints of the limbs specifically engaged in the task but also in the supporting structures of the back. The potential damage these torques inflict on the structures of the musculoskeletal system has been inferred from studies of tissue response to mechanical stresses, most notably compression on the spine.

Biomechanical studies enable us to estimate the local load on specific limbs while performing a task. Usually it entails filming the operator and then analysing the motion and posture using algorithms that have been derived from kinetic models. Electromyography often augments the video films.

Two types of biomechanical models exist—static and dynamic—depending on the kinetic and kinematic conditions they simulate. Static models of the load on the spine use the compressive forces acting on the vertebrae as a criterion to establish permissible loads, given certain job conditions. To calculate the torques, these models make use of the weight of the object handled (or the mass of the body part maintained in space), the size of the object (i.e. the distance of the centre of mass from the lumbar spine), and the angular configuration during the motion (i.e. angles of the trunk and the extremities in a coordinate system in space). In addition, biomechanical models incorporate anatomical data on moment arms of muscles and their lines of action to translate torques into muscular forces needed to counteract the torques. For example, Figure 1 shows the flexion torques created around the lumbar spine in two positions of the trunk. Knowing the lever arm of the erector spinae muscle, we can calculate that the force exerted by the muscle in position B is 3850 N, the compressive force acting on the disc would be 4382 N and the shear force is 373 N (Nordin and Frankel, 1989, pp 198–199).

Dynamic models use accelerations, besides the data required by static models, to calculate the forces that act on the spine. When this information is taken into account, larger torques are calculated, i.e. the loads on the spine are 30–60% higher than those predicted by static models. The dynamic component of spinal compression is the greatest when the trunk is moving

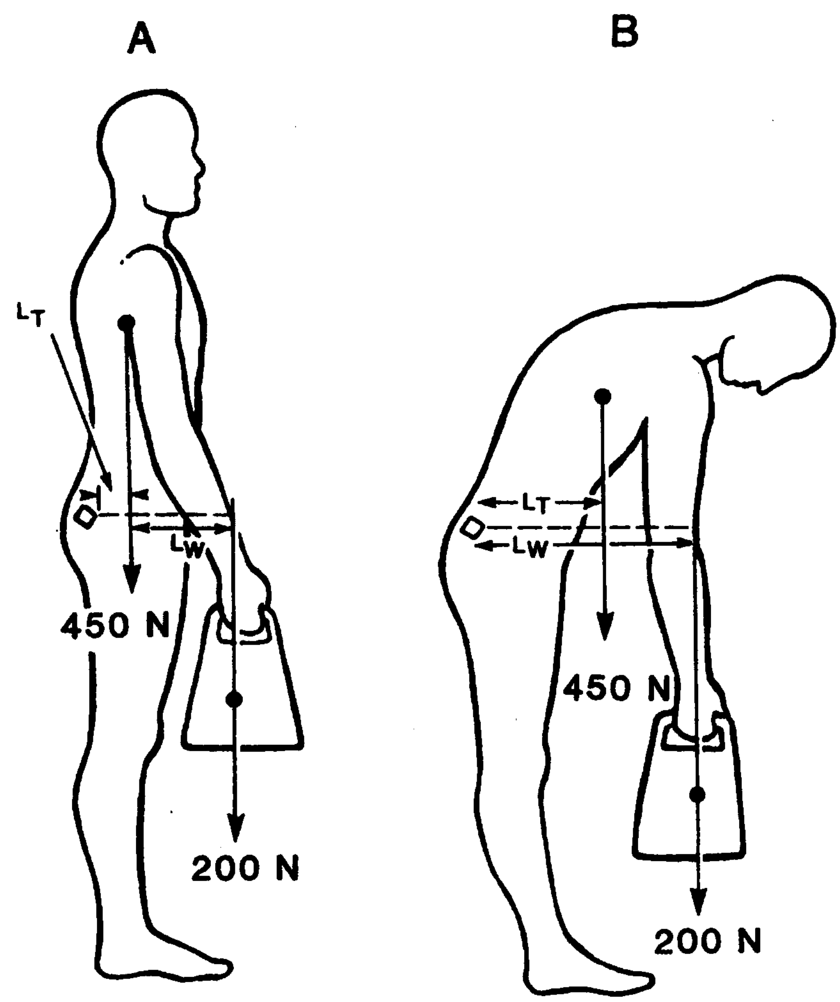

Figure 1. Flexion torques created around the lumbar spine in two positions of the trunk. L_t—lever arm of the trunk, L_w—lever arm of the object. Total forward-bending moment: A, 69 Nm; B, 192.5 Nm.

during the lifting task (Leskinen, 1985). In other words, any manual handling technique that entails trunk motion will have a significant dynamic component over and above the static load on the spine.

It is not clear how the spine tolerates loads that exceed the fracture point of the vertebrae without sustaining an injury. Other factors, such as intra-abdominal pressure, may reduce the load on the spine in vivo. Intra-abdominal pressure measurements have shown that the pressure rises with increasing flexion of the trunk, with dynamic lifting and with increased weight lifted (Nordin and Frankel, 1989). A statistical association has been found between intra-abdominal pressures measured on the job and prevalence of back injuries. The results were used by the British defence forces to establish safe limits for a variety of activities (Pheasant, 1991). These limits are based on empirical findings rather than an analytical model, therefore, they cannot be generalized beyond the specific activities measured.

By using changes in acceleration patterns (jerk), dynamic models direct attention toward the temporal dimensions of muscle recruitment. These developments attempt to explain the occurrence of LBP in tasks that did not require heavy weights. Thus, sudden and unexpected movements may be more harmful than the actual weight handled. Dynamic models offer insight into the attributes of unsafe behaviour, beyond establishing guidelines for permissible loads.

In an attempt to find attributes of unsafe behaviour, dynamic models offer insight into fatigue as a possible injury mechanism. For example, fatigue of the dorsal and abdominal muscles is compensated with secondary muscles: flexion/extension motions are increasingly coupled with lateral bending and rotations of the trunk. This finding suggests that it may be the change in motor coordination pattern that leads to unsafe exertions (Parnianpour et al, 1988).

Biomechanical models of the spine vary in sophistication and computation requirements. For example, Chaffin and Andersson (1984) proposed a static model that considers the action of three pairs of muscles. Schultz et al (1983) proposed a 22-muscle model that estimates the compression forces in asymmetrical tasks. The last model also makes various assumptions needed to deal with the fact that there are more variables (forces) than equations. The model assumes that the muscles of the trunk are activated in a way that will produce the lowest compression forces on the spine. Another assumption is that muscles do not co-contract.

The most useful application of biomechanical models of the spine is the establishment of acceptable safe limits for loads handled in lifting activities. Limits on lumbar spine compression have been used by the National Institute of Occupational Safety and Health (NIOSH) in the United States to develop lifting guidelines (NIOSH, 1981); similar features have been adopted by several states in Australia, and they may also be incorporated into the European (CEN) Standard. A practitioner, including an HCP, can use the guidelines for evaluating task demands during a walkthrough at the shop floor or by viewing photos and other documents. An example of its use appears in Appendix 1.

Results of the biomechanical approach should be interpreted with a basic knowledge of the simplification and assumptions that have been involved in the calculations. Thus the model used by NIOSH guidelines is appropriate only for static situations with symmetric lifting postures. The most serious limitation of the biomechanical approach is that it does not estimate the effects of fatigue due to repetitive exertions. Nevertheless, it provides a useful tool for evaluating manual handling tasks, highlighting problems and testing possible improvements. For further review see Tracy (1990) or Andersson, Chaffin and Pope (1991).

The physiological approach

This approach uses measures of oxygen consumption, metabolic rate and heart rate as indices of the energy required for performing the task. Whether it acts statically or dynamically, the muscle demands a supply of energy sources. These sources can be aerobic, i.e. using oxygen carried in the blood, or anaerobic, using pathways to metabolize glycogen. There is a limit to the amount of oxygen that can be supplied by the cardiopulmonary system. This limit is the maximum aerobic capacity or the physical fitness of the individual. This is the limiting factor in exercise where large muscle mass is involved. Anaerobic metabolism usually begins at 50% of the individual maximal aerobic power. Anaerobic metabolism is also involved in local muscular fatigue during static effort (isometric contraction) exceeding about 10% of the maximal muscle strength. The fatigue mechanism is the accumulation of lactate in the working muscle due to insufficient washout of metabolites (Kilbom, 1990). The onset of the latter mechanism is directly determined by the demands of the job. These include the weight of the load, the body posture and technique, the distance and frequency of motion, the duration of rest periods and environmental conditions such as temperature and humidity.

For most manual tasks, oxygen uptake is a good indicator of physical stress. Exceptions are tasks with a large static component, explosive activities which require a large anaerobic metabolism, and work under heat stress. For such activities oxygen uptake is an indicator of the aerobic component only. Heart rate, blood pressure and body temperature measurements are needed to supplement the information on the job demands. Localized overloading of specific muscle groups or soft tissue structures would not be detected with these measurements; invasive procedures are usually needed to measure local blood flow and accumulation of metabolites in the working tissue.

Besides lifting or lowering, manual material handling tasks consist of carrying, pushing and pulling activities. Combined tasks are limited by muscle strength and aerobic capacity. Tasks that require carrying in addition to lifting involve large muscle groups. The major contribution to the physical effort is the lifting of a load from the floor (this includes the weight of the trunk) rather than the carrying. When the lifting frequency is high, or the carrying distance is long, the limiting factor is the metabolic energy cost rather than the strength of the muscles involved (Taboun and Dutta, 1989). It is not clear yet whether the metabolic cost of combined tasks is additive.

The physiological approach can be useful for evaluating gross fatigue. NIOSH lifting guidelines include therefore metabolic rates as the framework for the biomechanical evaluation. The approach does not lend itself to establishing safety limits because physiological responses are dependent also on the fitness of the individuals. Consequently, the relationship between metabolic cost of work and LBP has not been clearly demonstrated, nor has the relationship between the aerobic fitness of individual workers and LBP.

The psychophysical approach

Psychophysical studies quantify the subjective tolerance of people to various exertions. Psychophysics deals with the relationship between human sensations and their physical stimuli. For example, audiometric evaluations are psychophysical measurements of hearing thresholds. Using psychophysics in lifting tasks requires the subject to adjust the weight of the load according to his or her own perception of effort. The final weight that the subject chooses represents the maximum acceptable weight of lift for a given job condition (frequency of lift, range of lift, box size, etc.).

The psychophysical approach is attractive to ergonomists. Psychophysical measurements have been used extensively for a large number of subjects since they are easy to administer. Their validity and reliability have been demonstrated for muscular exertions, cardiovascular demands and exposure to vibration. Finally, this approach is attractive because the ratings are not particularly sensitive to the age, gender or experience of the rater (Fleishman, Gebhardt and Hogan, 1984). This approach has been adapted to clinical settings in the PILE test (for example Meyer et al, 1988). However, the practitioner should be aware that psychophysical measurements overestimate the lifting capacity at higher frequency of handling (Fernandez, Ayoub and Smith, 1991), and that males tend to overestimate their capacity (Karwowski, 1991).

A series of studies performed at the Liberty Mutual Research Center (Snook, 1978) and Texas Tech University (Ayoub et al, 1978; Karwowski and Ayoub, 1984) are noted for their comprehensiveness in this regard. These studies investigated the acceptability of manual material handling tasks in terms of psychophysical stresses, and then related them to risk of low back injury. Models were developed to predict both individual and population lifting, lowering, pushing and pulling capacity for various ranges of lift, box size and frequencies for males and females.

There is a good agreement between the psychophysical method and NIOSH guidelines in assessing risk potential. Both methods predict the number of back injuries, number of lost time back injuries, and the number of days lost in low-risk jobs; the psychophysical method is more effective in differentiating moderate- and high-risk jobs. For medical expenses, both methods correctly identify low-risk jobs, whereas neither differentiates well between moderate and high-risk jobs (Ayoub, Selan and Jiang, 1987).

The psychophysical approach has been used to determine maximum acceptable limits of individual operators or patients. The Texas Tech University team developed also a Job Severity Index (JSI) which is the ratio of job demands to individual capacity. Thus, the JSI method has an advantage over the NIOSH method by directly providing procedures for employee placement based on individual capacity (Ayoub et al, 1987).

There are also some differences between the safety limits established according to biomechanical or physiological stresses and the psychophysical stresses. The transition from biomechanical limitations to psychophysical or physiological limitations may depend on the lifting height and frequency of handling (Ayoub, 1991).

Integrated models

Since the estimate of the biomechanical, physiological and psychophysical stresses requires different evaluation techniques, it is necessary to know when to use each approach. As a rule of thumb, the weight of the object handled on the job is of concern in low frequency of handling (under five lifts/minute); the cardiovascular fitness of the worker becomes the concern at high frequency of handling. A biomechanical approach is useful for the former; a physiological or psychophysical approach is useful for the latter. Also, handling of materials from floor level up (rather than from waist level) is of concern for the lower back (Ayoub, 1991; Gagnon and Smyth, 1991). These rules can help a practitioner such as an ergonomist or an HCP to choose the most appropriate approach to evaluate task demands.

Physiological and biomechanical approaches can be combined to a single model using energy measurements as the linking variable. Kinetic measurements derived from video analysis and force plates can yield estimates of mechanical energy transferred between body segments. Physiological measurements yield information on metabolic energy expenditure. The ratio between the two measurements can serve as an index of efficiency. An integrated model would study performance efficiency during different combinations of manual material handling tasks. This model could have practical applications that would interest ergonomists and clinicians. For example, the model suggests that the maximum energy efficiency would be achieved under a combination of loads of 11–19 kg, frequency of 3–4 handling/min, and carrying distance of about 10 m (Dutta and Taboun, 1989). These data can serve as criteria for evaluating the demands of manual material tasks.

Most of the literature on the occupational hazards associated with LBP focuses on peak work-loads as the possible cause of injury to the spine. This direction may be motivated by epidemiological surveillance efforts designed to monitor acute traumas. In recent years, occupational safety and ergonomics specialists have begun to shift their attention to evaluating the cumulative effects of exposure to hazards. The biomechanical and physiological approaches have not yet been successfully used to establish valid models for evaluating subacute job demands. Similar difficulties are encountered by clinicians attempting to diagnose and treat subacute musculoskeletal disorders, including some classes of LBP. An analysis of 3 years of medical data for 6912 workers in the manufacturing industry can give us some insight into the evaluation of peak versus average work-loads. Peak mechanical stresses were slightly better correlated with both the incident rate and severity of all types of musculoskeletal and overexertion injuries. Low back disorders were better correlated with average job stress than with peak stress ratings. At this point, it appears that the risks of both acute and cumulative traumas to the low back must remain the concern and multiple work evaluation procedures need to be applied (Chaffin et al, 1991).

Job analysis methods for the workplace and the clinic

Traditional job analysis methods use performance prediction procedures such as Motion Time Measurement (MTM). These methods break the task into generic elements (reach, move, grasp, etc.) and measure the time it takes to perform each element. The generic elements used by the MTM method have been defined primarily for tasks involving the upper extremities. To describe the trunk, the method includes items such as 'walk' or 'turn body'. From an ergonomic viewpoint, the major shortcoming of these methods is that they are designed to account for average job performance. They do not consider infrequent or non-routine operations (typically those that take less than 5% of the total workday). Yet many accidents or injury reports suggest that these tasks account for a large number of injuries and often involve maximal exertions (Chaffin et al, 1991).

Contemporary ergonomic analyses use the traditional industrial engineering methods together with additional ones to document job demands. Direct measurements of job demands require respirometry, motion analysis, electromyography, heart rate monitors, etc. These measurements are intrusive, costly and complicated. Their results, however, can be translated into a set of risk factors predicting LBP, and be incorporated in other methods. Consequently, the most common and practical methods consist of stress checklists and surveys. A comprehensive review of recent developments in ergonomic job analyses is provided by Landau and Rohmert (1989). A checklist designed to document job demands that are associated with LBP is provided in Appendix 2. In a clinical setting, this form could be filled out by the injured worker.

The tools that measure the magnitude of the job demands use scales that are rated by expert observers or by the workers themselves. An example of the former is the Ergonomic Job Analysis known by its German acronym AET (Rohmert and Landau, 1983). Other techniques are available, such as the Profile de Postes, developed for Renault company (Wagner, 1985). Appendix 1 contains an example of a simple scale of lifting demands adapted from NIOSH guidelines to be rated by observers or the workers.

Questionnaires based on worker ratings do not require the training that observer-based methods need but they are intrusive. They also encounter recruitment or response problems. Injured workers are a readily available source of information on job demands. However, worker self-reports after injury may be biased. An indirect method that uses active workers to rate job demands offers an alternatve. One method for classifying the physical

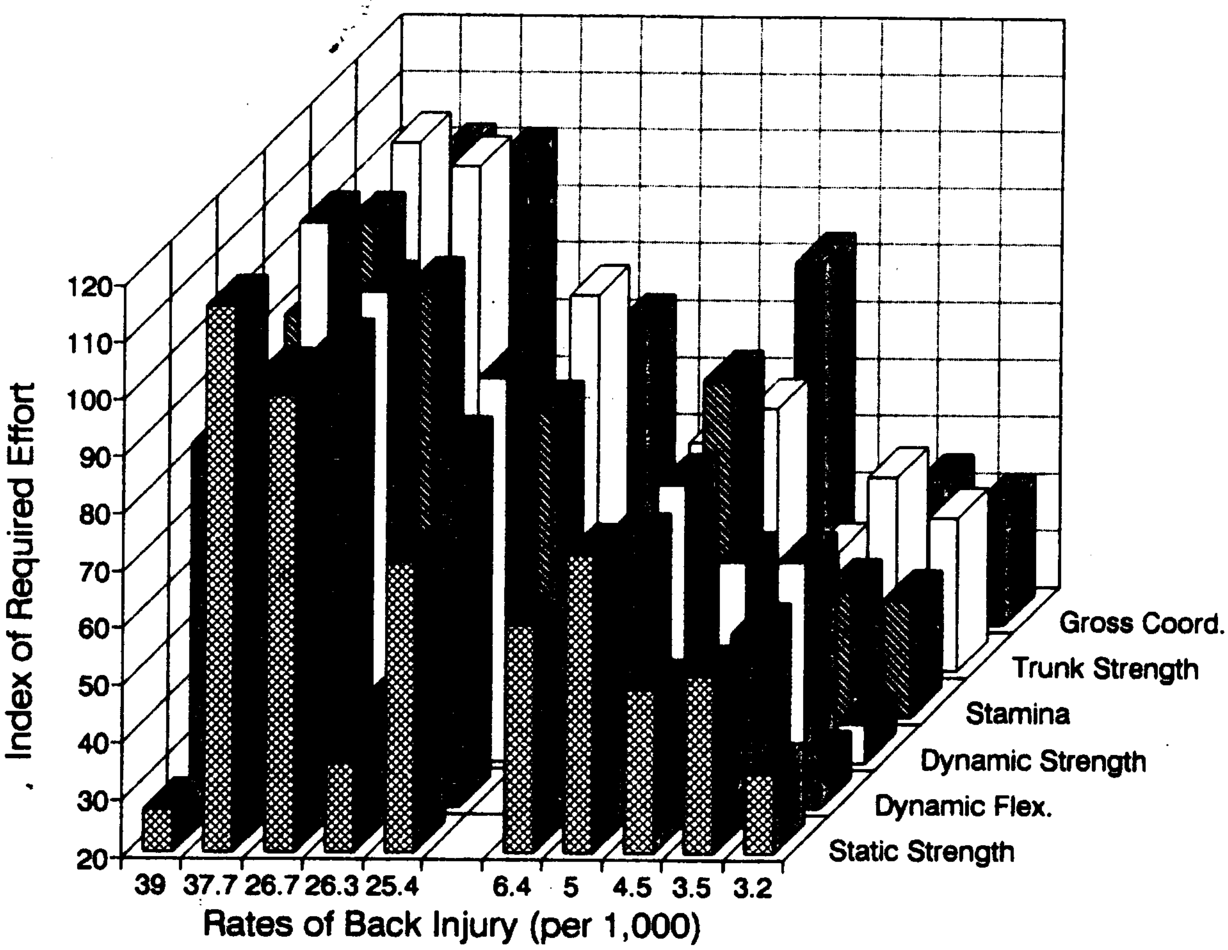

Figure 2. The distribution of effort required in six physical abilities of five jobs having high back injury rates and five having low back injury rates.

demands relies on a taxonomy of generic abilities. Subjects rate on psychometric scales the amount of effort, frequency and importance of the physical ability required by a task (Fleishman, 1978; Hogan et al, 1980). The ratings of several physical abilities correlate with the incidence of back injuries (see Figure 2). These abilities include static and dynamic strength, trunk strength, stamina, dynamic flexibility, gross motor coordination and balance. The results suggest that worker ratings of physical effort are valid as predictors of back injury risk (Skovron et al, 1991). These types of physical effort should be at the core of a task evaluation that is relevant for LBP. Their use at the worksite or the clinic will be discussed below.

The decision regarding the appropriate evaluation method depends on the type of intervention that is planned. Job evaluation for workplace design requires an emphasis on the equipment used and the work conditions; job evaluation for placement of injured employees emphasizes the operational demands of the tasks. Implications of these decisions are illustrated in the following section.

ERGONOMIC INTERVENTION—STRATEGIES AND EFFECTIVENESS

The strategies of health control intervention depend on the category of LBP prevention. This section discusses, using examples, strategies for reducing musculoskeletal risks and how to evaluate their effectiveness in primary and secondary prevention programmes.

Primary prevention in the workplace

The results of the studies that used biomechanical, physiological and psychophysical approaches to measure physical effort at work suggest that an ergonomic intervention should address the following parameters to prevent LBP:

Parameter	*Example*
1. Loads	the weight of the object handled
2. Object design	the size of the object handled, the shape, location and size of handles
3. Lifting technique	the distance between the centre of gravity of the object and the worker, twisting motions
4. Workplace layout	the spatial features of the task, such as carrying distance, range of motion, obstacles, such as stairs
5. Task design	frequency and duration of the tasks
6. Psychology	job satisfaction, autonomy and control, expectations
7. Environment	temperature, humidity, noise, foot traction, whole-body vibration
8. Work organization	team work, incentives, shifts, job rotation, machine pacing, job security

Most ergonomic intervention programmes that aim at reducing musculoskeletal risks modify the first five parameters. The principles of an intervention that addresses these parameters are listed in Appendix 3. The effectiveness of the last three parameters in preventing musculoskeletal disorders has not been studied methodically. A comprehensive review of the effectiveness of each parameter is beyond the scope of this chapter. Nevertheless, the following includes a few examples.

However reasonable, the effectiveness of ergonomic intervention in controlling LBP health care costs or morbidity has not been clearly demonstrated. Practical problems prevent researchers from isolating the effects of ergonomics from other factors that intervene and influence performance during the data collection period. Considering the prognosis of occupational musculoskeletal disorders, in particular LBP, a study period of one year would probably be necessary to monitor changes in musculoskeletal problems, and avoid the incursion of confounding factors.

One approach relies on epidemiological data to evaluate the effectiveness of job design in reducing injuries. A classic study investigated 191 cases of low back injury. Questionnaire results revealed that about 25% of the jobs involved highly demanding manual material handling (psychophysically acceptable only to 75% of the workers). The workers engaged in heavy lifting jobs were three times more susceptible to low back injury. It was estimated that, at best, two out of three low back injuries associated with heavy material handling could be prevented if the tasks were designed to fit at least 75% of the population (Snook, Campanelli and Hart, 1978).

The potential efficacy of workstation modifications usually requires a careful job analysis. This analysis estimates the degree to which manual material handling tasks are determined by the physical design of the station. Some studies estimate that 20–40% of the lifting motions are due to individual worker handling technique (Drury, 1985; Chaffin et al, 1986; Hale and Mason, 1986). It is possible that mainly twisting motions can be avoided using different handling technique such as turning the entire body (Chaffin et al, 1986). If approximately 60% of back injuries could have been avoided (Hale and Mason, 1986), then proper training is still useful, at least in those workstations where workers twist their trunk while performing manual material handling tasks. Other motions, i.e. flexion and extension of the trunk, may be avoided through engineering solutions. Figure 3 shows how a simple workstation redesign may reduce the static load on the lower back, the neck and shoulder, and improve the viewing conditions.

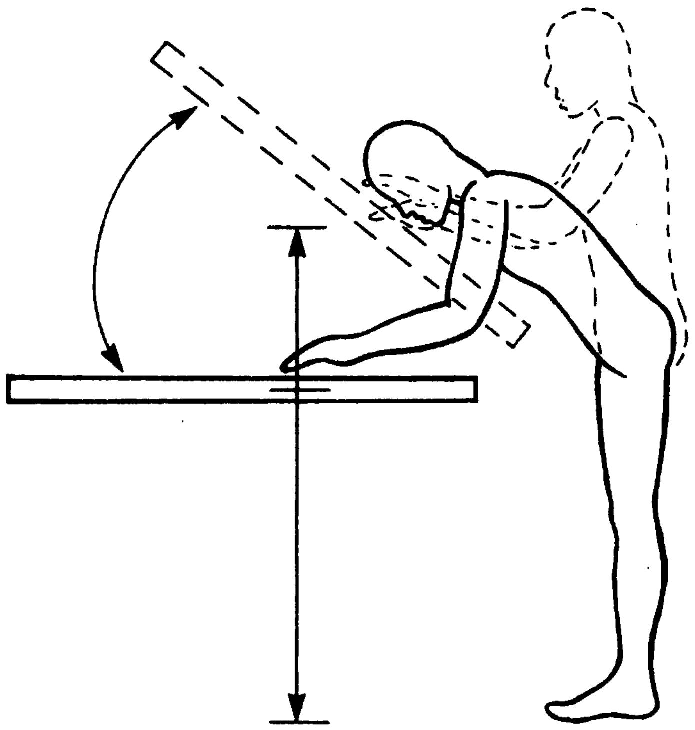

Figure 3. Tilted work table reduces flexion of the neck and lower back.

During an ergonomic intervention programme that involved the workers in a large automobile parts plant in the United States, various projects were implemented to reduce musculoskeletal stress. The degree of stressfulness for the lower back was reduced by 40% according to NIOSH guidelines. The changes affected machining on very large stationary equipment and heavy casting and were therefore costly. A study period of one year was not sufficient to note any changes in injury rates; cost–benefit analysis was not reported (Joseph, 1986). A similar 2-year intervention in a larger car assembly plant reduced the number of people reporting symptoms of cumulative trauma to the back and upper extremities from 6.5 to 3.2%; back symptoms were a third of all the complaints. This reduction of 50% in clinical visits occurred in the department where the heaviest material had been handled. In other words, jobs that require heavy lifting would benefit most from ergonomic interventions. A control group (in a different department) experienced a slight increase of reported symptoms (Lifshtiz et al, 1989).

One comprehensive intervention programme implemented in a Norwegian telephone plant included a rare cost–benefit analysis. Motivated by complaints of neck, shoulder and low back pain, and high rates of sick-leave and labour turnover, the company initiated ergonomic interventions over a period of several years. A clinical follow-up was conducted over a period of more than 8 years. The ergonomic interventions included changes in workstation design, such as tilting of the cabling work surface platform (see Figure 3 for example) and improved seating. Later modifications included redesign of the lighting and ventilation systems. Redesigning the workstations and the lighting reduced the static load on the trapezius muscles, particularly for standing tasks, from 4–6% to about 1% of maximal voluntary contraction (MVC). The total investment came to about US$57 000, 70% of which was allocated to workstation modification. This investment produced a significant reduction of direct costs of about US$490 000 in a period of 8 years. The savings were due to reduced musculoskeletal sick-leave (from 23 days to 2) and reduced turnover (from 30 to 8% of total man-labour years). Productivity was not included in the calculation of the savings. The fluctuations in productivity were affected by market conditions and changes in the pay system (Westgaard and Aarås, 1985; Aarås et al, 1990). Similar studies still need to be done specifically for the prevention of LBP.

In the examples above, specific solutions were obtained through a detailed workstation analysis. To develop organizational intervention strategies, a different approach may be more practical. Methods such as the AET, that use generic descriptors to categorize jobs in terms of their demands offer public health administrators a broad view of the organization, while satisfying the ergonomist's need for detail. They tell us what are the critical areas that need to be examined more closely, and from this we can decide what technique to use.

Figure 2 shows that while physical effort is generally associated with back injuries, not all jobs with high back injury rates require the same physical abilities. For example, one high-risk job (car painting) required stamina, dynamic flexibility and dynamic strength; another high-risk job (truck maintenance) required balance, gross coordination and static strength. The results illustrate the multifactorial aetiology of occupational back injuries and the diverse demands of high-risk jobs (Halpern et al, 1991).

Although environmental conditions need to be incorporated into the analysis, the interim results also suggest that the method may have a resolution of details that is useful for outlining intervention strategies. Here are some examples (Halpern et al, 1991).

1. The tasks that were rated highest for stamina requirements entailed carrying materials up and down stairs, skilled activities that involve the

upper extremities (brick laying, sanding, finishing concrete), and frequent climbing (more than 4 m). A back injury prevention programme in these jobs should focus on administrative measures and aerobic conditioning of employees.

2. Several tasks that impose high postural demands on the trunk (trunk strength), such as tightening or loosening of bolts, also require special tools. These tasks could be targets for ergonomic modifications.
3. Tasks that required high effort of manual material handling (static strength) entailed hourly and daily lifting, lowering, pushing or pulling of loads over 25 kg. These tasks could benefit from administrative and engineering controls.

In general, jobs which place high dynamic demands (heavy work, frequent handling of heavy material and dynamic use of the limbs) may benefit from ergonomic interventions that address mainly the first five parameters listed earlier in this section. Reducing peak loads may be most beneficial. Jobs that require primarily static muscular effort (prolonged sitting, maintaining a fixed posture, not necessarily an awkward posture) may benefit from restoring motion throughout the workday. The dynamic component of work can be increased by restructuring the job, e.g. rotation, job enrichment. The layout of workstations may have to be changed to require the worker to move around; for example, in a Video Display Terminal (VDT) workstation, placing a filing cabinet further away from the seat will force the office worker to get up and move.

Because the association of LBP to the workplace is weak, occupational risk factors may be more important for evaluating disability than predicting the risk for injury (Andersson, 1991a Ch. 11). Job familiarity can be useful in clinical settings involved in the secondary prevention of LBP, mainly in designing return to work programmes, for placement and accommodation of injured workers, and for the prevention of re-injury.

Secondary prevention—accommodation and placement

Primary prevention programmes that require global changes in the workplace may yield high savings in costs but they require large budgetary allocations up front. Accommodation for individual injured workers may be cheaper. A survey of companies that have done so shows that 50% of accommodations involve no cost, while another 30% cost less than US$500 (cited in Wiesel, Feffer and Rothman, 1985).

The evaluation and documentation of job demands represent the beginning of a systematic approach to rehabilitation, accommodation and job placement. They provide a common framework on which specialists can base their various contributions. It focuses on matching between worker capabilities and job demands. Little research has been directed towards the development of ergonomic job evaluation techniques that offer structured, compatible means for assessing the individual rehabilitees. A scheme is needed that will comprise the following:

1. A job demands evaluation technique.
2. A personal ability assessment technique.
3. A communication system that relates the two techniques.

After a review of existing techniques, including the AET and the Profile de Postes, the British Steel Corporation (BSC) has developed its own scheme to improve rehabilitation services. A pilot study evaluated the match between job demands and the abilities of active employees successfully doing the job. 'Not recommended' or 'unacceptable' matches would have indicated the inadequacy of the technique rather than an inability of the individual to do the job. The results of the evaluation confirmed that 85.5% of all items fell within the categories of 'ideal', 'acceptable' and 'possible' matches. On the strength of this finding the system was considered adequate for placement decisions (Watson et al, 1984). A similar approach should be used to evaluate the appropriateness of other ergonomic questionnaires to clinical settings.

An ergonomic job analysis appropriate for a clinical setting could also be based on Fleishman's method, described above, that rates the physical abilities required on the job. In a clinical setting, the rating could be done by the injured workers. It is not clear yet whether LBP patients would rate these demands in the same way as active workers. Job profiles similar to the examples shown in Figure 2 can be constructed from patient interviews and the results would guide the HCP in setting rehabilitation goals, or designing work hardening programmes. In either case, the goal is to design job-specific programmes.

A similar procedure has been in use in Germany since the mid-1970s. The ERTOMIS Assessment Method matches a profile of patient abilities with a profile of job requirements. Both profiles use 65 identical generic descriptors divided into seven categories: upper and lower extremity motion and coordination, basic postures and motions, sensory abilities, mental abilities, communication abilities, tolerance of environmental conditions, and leadership abilities. The method is designed to provide a framework for job placement, facilitate communication among the participants in the rehabilitation process, and focus the rehabilitation process on job issues. If implemented in the context of a larger model, ergonomic job analysis methods like ERTOMIS can play a leading role in prevention by using ergonomic principles in workplace design; in early intervention, by focusing on the mismatch between patients' abilities and job demands; and in case management, by providing job descriptions that are meaningful to the HCP as well as the employer (Frey and Nieuwenhuijsen, 1990).

When health care services are fragmented, as often happens in the United States, the effectiveness of the method is reduced. A pilot study suggests that the ERTOMIS and similar methods may be useful for job placement in complex cases, and less effective in cases with musculoskeletal disorders that are the result of cumulative trauma. In complex or severe cases, the method resulted in cost savings. Interestingly, unsuccessful cases (drop-out after initial placement) did not end in court of law. Preliminary trials indicate that ergonomic procedures would be useful for secondary prevention within rehabilitation settings that also provide placement services. It may not be effective for primary health care facilities in industrial settings.

IMPLEMENTATION OF ERGONOMIC INTERVENTION

How do we structure the ergonomic intervention? The implementation of ergonomic interventions has to address management concepts and operational policies. These concerns depend on the category of prevention that we choose. Lessons regarding primary prevention can be learned from ergonomic intervention programmes that had been implemented in the industry.

Issues in implementing ergonomics in the workplace

Since ergonomics is multidisciplinary, its implementation involves many functionaries in an organization. However, due to their operational responsibilities, organizational units often act as a barrier to setting up ergonomics in the workplace.

One mechanism for making changes, despite the organizational barriers, is the creation of task forces that bring together functionaries from diverse units and backgrounds to solve specific problems. Ergonomic problems typically require the participation of representatives from the human resource department, medical services, safety personnel and operations. Task forces exist for the duration of the problem-solving process. They would therefore be effective in situations where a problem is already identified and a solution is sought.

An effective prevention strategy requires that the organization establish a mechanism for identifying potentially hazardous areas, evaluating the scope of existing problems and finding solutions. In that sense, ergonomics is a continuous process rather than a solution.

A feature that distinguishes between various task forces is the degree of involvement of workers in developing solutions. Participation has long been recommended by many concerned with issues of organizational design. Ergonomists have traditionally sought worker participation to identify problems and elicit solutions. There are many examples for participative ventures in the ergonomics literature. We can identify at least three types of participative strategies in work design (Wilson and Grey, 1986):

1. Use of worker groups to design their own workstations.
2. Development of interview and questionnaire methods to elicit job design data.
3. Setting up semi-autonomous working groups to implement technological and organizational change.

Participative strategies have been adopted by many organizations concerned with improving the quality of services and production. Existing worker groups such as Quality Circles could include ergonomic issues on their agenda. In the past, health and safety issues had not often been discussed in Quality Circles in Japan, where the idea originated (Lifshitz et al, 1989). However, worker groups have been effective in improving accident surveillance and prevention (Carter and Menckel, 1990). The extent to which employees can realistically participate in resolving organizational issues is open to question. With concrete ergonomic issues such as workstation design it may be easier to reach an agreement than with payment issues.

Ergonomic interventions have been effective in imparting factual knowledge to management and workers about occupational risk factors involved in musculoskeletal disorders, and in documenting ergonomic problems. In general, they raise the awareness that ergonomic issues relate to health risks. The training programmes are less effective in teaching problem-solving skills. Clearly, training material has to be relevant to the trainees and context-specific. An effective technique for teaching these skills has not yet been found (Liker et al, 1990; Silverstein et al, 1991). This limitation would not affect the HCP to the same degree since their knowledge about the job would rarely be applied to finding engineering solutions.

Effective use of ergonomics must extend beyond training. Organizational approaches must be supported and nurtured. Ergonomics committees have to be invested with authority in addition to responsibility. Middle managers have traditionally been left out of participative approaches, at least in the United States; their support needs to be actively solicited because they are directly responsible for organizational performance.

Health outcomes of the participative strategy in ergonomic interventions require a long-term follow-up. Passive surveillance systems may not be sufficient to determine the success of the intervention. Active surveillance can provide more immediate results regarding pain, fatigue or discomfort. In the short run, other outcomes may be measured, such as reduction of ergonomic job demands and efficacy in introducing changes, e.g. length of time necessary to complete a project.

An example of implementing a participative strategy is provided by Joseph (1986). In an intervention programme at a large automobile parts plant of 1700 employees, 42 projects were initiated by one ergonomics group in the first year, and about half were actually implemented. A similar 2-year intervention reported by Lifshitz et al (1989) experienced 7–8 modifications each month. All implemented projects involved the workers. Once a decision was made to carry out a project, it took 30–60 working days to carry those projects that did not need the approval of higher management. The workers found the ergonomic modifications very usable. Their participation in the solution probably contributed to their acceptability.

The experience of participative strategy in ergonomic interventions also suggests that a combination of task force and worker group would be more efficient than separate groups (Joseph, 1986). Where semi-autonomous employee problem-solving groups already exist, their agenda may be too crowded to include ergonomic issues (Lifshitz et al, 1989). Also, the role of an advisory committee is very important to the programme's success. By monitoring and setting policy, the committee standardizes the goals and helps in allocating resources.

The task force is the framework in which an HCP should participate, particularly during a walkthrough evaluation at the workplace. This is how the HCP would become familiar with the job and help identify occupational risk factors for LBP. Walkthrough can also aid in determining work relatedness of an injury and return to work placement. It is rare that physicians take part in workplace walkthrough evaluation. Other HCP, mainly physical therapists and occupational health nurses, have a crucial role in obtaining job familiarity.

Current trends in participative strategies emphasize Total Quality Management (TQM). Quality typically starts with understanding customer requirements. This can be expanded to include the physical and psychological requirements of the 'internal customers', i.e. the employees. This approach could be used to raise the awareness that ergonomic problems may also relate to quality issues. Accordingly, products that evoke musculoskeletal complaints among the workers on the assembly line, may also cause problems among clients who have to maintain the products. The notion may be more relevant to musculoskeletal problems that result from cumulative trauma rather than acute problems and could be applied to LBP as well.

Issues in implementing ergonomics in a health care facility

The implementation of ergonomics in a secondary prevention programme encounters similar issues. An organization that adopts a policy of rehabilitation rather than compensation must provide a good means of communication between the various people involved in the rehabilitation process. Ergonomic methods can be used to evaluate the job demands of the patient visiting a health care facility.

In case management, the HCP faces work-related questions during several stages of the process:

1. Based on job demands, is accommodation required?
2. If so, what accommodation alternatives are feasible?
3. If engineering solutions are not reasonable, is restricted work assignment possible?

To answer these questions in a clinical setting, the HCP needs the co-operation of several organizational units. These units must develop communication procedures to facilitate the placement process. An organization that adopts the TQM approach would be more likely to view the placement process as part of the improvement in internal services. According to this approach, there is a reciprocal interaction between the units involved in the rehabilitation and placement of returning employees.

Ultimately, the success of the vocational rehabilitation process rests on the line supervisor and the returning worker. Usually, physicians provide the line supervisor with generic instructions such as 'No lifting', or 'No stooping'. The line supervisor and the returning worker have to interpret the instructions. If detailed job descriptions are available in terms that help medical decision-making, the HCP could share the burden of interpretation by furnishing the supervisor with job-specific guidelines.

The success of the accommodation to individual employees, or the restricted duty assignment, depends also on co-worker support for returning workers. This is particularly important in team work. Experience from implementing placement methods such as ERTOMIS shows that the medical officers are expected to solve emotional and social issues that arise during the placement process. Low back patients probably fall in that category of patients who return to the clinic because of lack of co-worker support. These are not medical issues. Therefore, the medical officers may not be trained to deal with them. When health care is fragmented, HCP lack complete understanding of the rehabilitation and placement process; they would not see the value of job familiarity in their domain.

The resistance of HCP to implementing ergonomic methods is partly the result of a lack of knowledge. Future effort should address this lack of expertise in interpreting ergonomic data. Knowledge distribution systems that combine expert advice with database management offer a promising strategy for disseminating information on health control measures. Computerized systems can be developed to match profiles of job demands with data on the impact that LBP has on the physical abilities of impaired workers or their tolerance to certain work conditions. Such expert systems can reduce the time needed to retrieve the information and they can present the information in ways that would be relevant for placement decisions.

SUMMARY

Redesigning the job is a strategy for preventing low back injuries at work or for accommodating injured employees who return to work. An evaluation of the physical job demands is necessary in either strategy. Several job demands are associated with low back pain and injury—heavy physical work, static or postural effort, dynamic work-load and exposure to whole-body vibration. Traditional work measurement studies emphasize a rigorous task analysis. By adding biomechanical, physiological and psychophysical measurements, a comprehensive evaluation is possible. There is no standard scheme for a workplace evaluation. The method depends on the end use of the analysis. Job evaluation for workplace design requires an emphasis on equipment and work conditions; evaluation for placement of injured employees should emphasize the operational demands of the tasks. Few studies considered the multifactorial aetiology of low back pain. Most studies that measured the magnitude of biomechanical, physiological and psychophysical stresses attempted to define peak work-loads. The attempt to evaluate the effects of subacute cumulative traumas is only in the beginning.

Most ergonomic intervention programmes modify the loads, the design of objects handled, lifting techniques, workplace layout and task design. The effectiveness of these interventions in controlling medical costs or morbidity has not been clearly demonstrated. Consequently, occupational risk factors may be more important for evaluating disability. *Job familiarity is the key to effective medical management.* Ergonomic analysis procedures may be

useful within rehabilitation settings that also provide placement services. The reason is that they facilitate communication between all elements involved in the rehabilitation process. Proper communication procedures are also crucial in implementing ergonomic interventions in the workplace. A health care provider should be part of a task force that oversees these interventions.

Future effort should be directed to finding a method that health care practitioners could be competent to carry out effectively in a clinical setting. Expert systems offer promising results in disseminating ergonomic knowledge in primary and secondary health care facilities.

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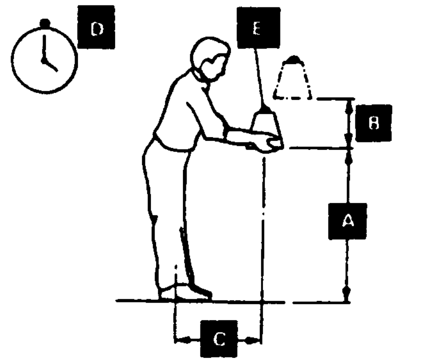
APPENDIX 1: EVALUATION OF LIFTING SAFETY LIMITS

STEP 1. Answer Yes to These Before Proceeding

- Is the task using both hands equally? ☐ Yes ☐ No
- Is the lifting in front of the body and in unrestricted space? ☐ Yes ☐ No
- Is neither the work surface nor object slippery? ☐ Yes ☐ No
- Does the task involve lifting a compact load (less than 75cm in width)? ☐ Yes ☐ No
- Does the lifting <u>not</u> involve walking more than four steps with the object? ☐ Yes ☐ No

If the answer to any of these questions is No, *then this form should not be used*

STEP 2. Measure:



For dimensions between those listed in the tables it is permissible to estimate between the two corresponding factors given.

STEP 3. Calculate:

A

Height at Start (cm)	Factor
0	0.70
25	0.80
50	0.90
75	1.00
100	0.90
125	0.80
150	0.70
175	0.60

B

Vertical Distance (cm)	Factor
25 or less	1.00
30	0.95
40	0.89
50	0.85
70	0.81
150	0.76
200	0.74

C

Horizontal Distance (cm)	Factor
15	1.00
20	0.75
25	0.60
30	0.50
40	0.37
50	0.30
65	0.23
80	0.19

D

• Manual lifting at these frequencies is not recommended and this section should not be used. Refer to section 7.1.

Time Between Lifts	If worker is standing, use these columns		If worker is stooped, use these columns	
	For one hour or less of lifting, use this column	For over an hour of lifting, use this column	For one hour or less of lifting, use this column	For over an hour of lifting, use this column
	Factor 'D'	Factor 'D'	Factor 'D'	Factor 'D'
5 mins	1.00	1.00	1.00	1.00
1 mins	0.94	0.93	0.93	0.91
15 secs	0.78	0.73	0.73	0.67
9 secs	0.63	0.53	0.53	0.44
6 secs	0.44	0.33	0.33	0.16
5 secs	0.33	0.20	0.20	•
4 secs	0.17	•	•	•
3.3 secs	•	•	•	•

☐ × ☐ × ☐ × ☐ × 40 = **F** ☐

STEP 4. Compare:
If the actual weight E is more than the weight F, then the task should be modified

(Adapted from Occupational Health and Safety Manual Handling Regulations, 1988 of Victoria, Australia)

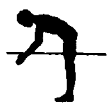
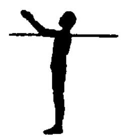
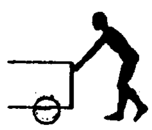
APPENDIX 2: BACK PAIN RISK EVALUATION CHECKLIST

Work Location ______________________

Task Description ______________________

Employee Age & Sex ____________ Assessed by ____________

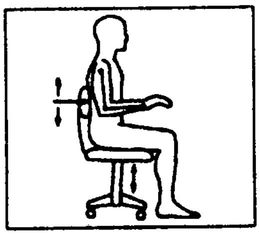
A "YES" answer to any of the risk factors in the list indicates the need for further assessment:

		Yes	No
Posture			
1. Is there prolonged or frequent twisting and side bending of the trunk?		☐	☐
2. Is there prolonged or frequent forward bending of the trunk below mid-thigh height?		☐	☐
3. Is there prolonged or frequent forward bending of the trunk with the arms extended to reach forward (50 cm away from the ankle)?		☐	☐
4. Is there prolonged or frequent reaching above the shoulder?		☐	☐
5. Is unbalanced or uneven lifting\carrying involved?		☐	☐
Task and Object			
6. Is the object difficult to grip - bulky, unstable, no handles?		☐	☐
7. Is there pushing\pulling of loads at heights other than hip level?		☐	☐
8. Is there frequent lifting of loads from floor up (more than 5 lifts/min)?		☐	☐
9. Is there frequent carrying of loads more than 10 meters?		☐	☐
10. Is the weight of the object: • More than 4.5 kg and handled in seated position		☐	☐
• More than 20 kg handled in working posture other than seated?		☐	☐
11. Are there signs of heavy breathing at frequent and prolonged lifting and carrying tasks?		☐	☐

Appendix 2 continued overleaf

Work Environment

12. Is the task performed in a confined space?	☐	☐
13. Are the floors full of obstacles?	☐	☐
14. Are the floors very rough?	☐	☐
15. Are the floors slippery with oil or water?	☐	☐
16. Is the lighting inadequate for safe carrying?	☐	☐
17. Is the height of the chairs unadjustable?	☐	☐
18. Is the chair without a back rest or unadjustable back rest?	☐	☐
19. Is the chair without arm rests?	☐	☐
20. Are there unpadded seats mounted on vibrating vehicles?	☐	☐



APPENDIX 3: PRINCIPLES OF MANUAL MATERIAL HANDLING WORK DESIGN

1. Eliminate the need for heavy tasks; this is the optimal solution
   - —Use mechanical aids, for example, lift tables, lift trucks, hoists, cranes, conveyors, gravity dumps, chutes.
   - —Change layout of work area, for example, change height of work level or worker level, provide material at work level.

2. Decrease job demands: this approach should be used when heavy tasks cannot be eliminated.
   - —Decrease weight of object, for example, assign more than one person to the task, distribute load among several containers, reduce the weight of container.
   - —Change type of activity, for example, change from lifting to lowering, change from carrying to pulling, change from pulling to pushing.
   - —Change layout of work area, for example, reduce horizontal distance between lift start and end points (increase height of start point, decrease end point), limit stacking height to operator's shoulder level, place heavy objects at operator's knuckle height, minimize travel distance (< 10 metres).
   - —Allow more time to perform the tasks, for example, reduce frequency of lift, set work/rest schedules, rotate operators between tasks that do not use the same body limbs.

3. Minimize stressful body movements
   - —Reduce bending motions, for example, change height of work surface, provide material at work level, avoid deep shelves, locate objects within arm reach.
   - —Reduce twisting motions, for example, locate objects within arm reach, provide sufficient space for entire body to turn, provide seated operators with swivel chairs.
   - —Allow safe lifting motions, for example, allow handling close to the body (change shape of object or provide better access to object), provide handles for gripping the object, balance contents of container, provide rigid container, avoid lifting wide objects (>75 cm) from floor level.

(Adapted from Ayoub, Selan & Jiang, 1987)

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