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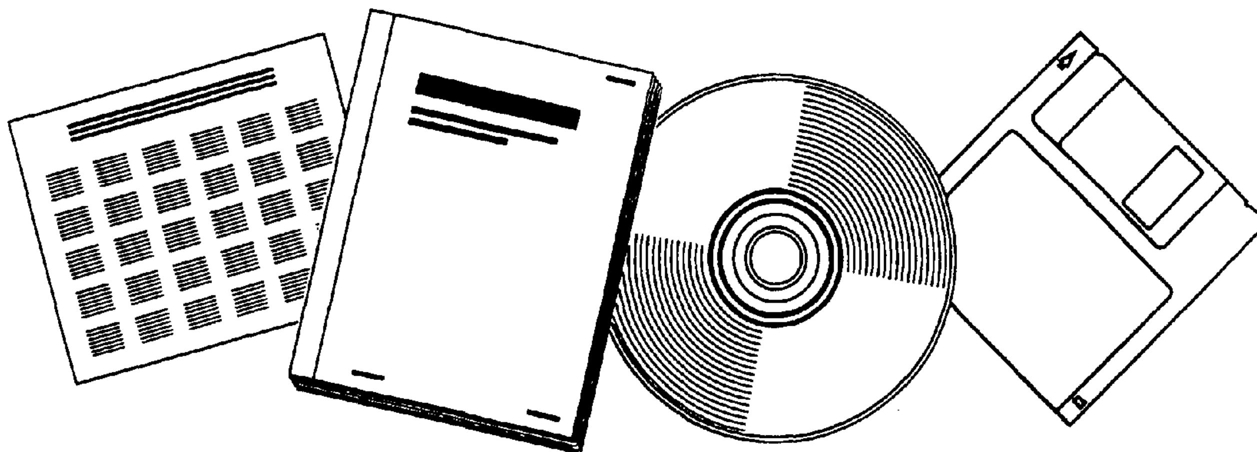

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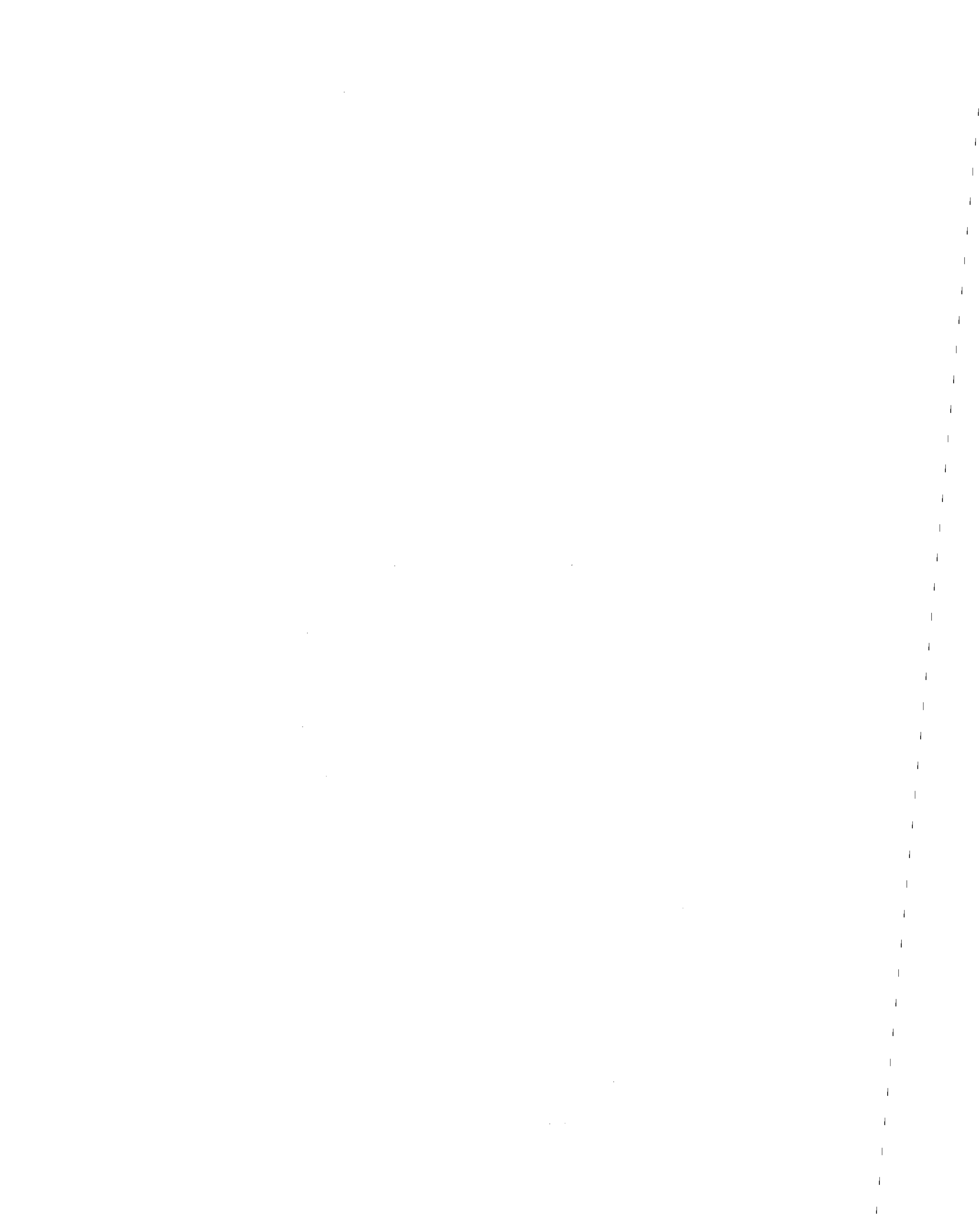

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RECOGNITION OF MUSCULOSKELETAL INJURY HAZARDS FOR THE UPPER EXTREMITY AND LOWER BACK

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ABSTRACT

This monograph summarizes techniques described in the published literature for recognizing upper extremity and lower back musculoskeletal injury hazards in the workplace. The emphasis is on techniques that identify and quantify, subjectively or objectively, job and/or work place risk factors. It is not the intent of this document to provide solutions or procedures to control these risk factors, even though specific recommendations have been made from time-to-time to mitigate the risk factors.

The relationship between the various occupational risk factors and musculoskeletal injuries and disorders is presumed in this monograph. Even though the evidence linking these risk factors and musculoskeletal injuries/disorders may not be direct, there is strong evidence associating many job and work place descriptors with musculoskeletal injuries and disorders.

The prevalence of musculoskeletal disorders in the work place and economic burdens associated with them are first briefly discussed. Next, a listing of widely recognized risk factors is presented, followed by a brief discussion of the actions that should be taken to control (eliminate or minimize) the adverse effects (musculoskeletal injuries and disorders) of these risk factors. Finally, the hazard recognition techniques are briefly described. These techniques are grouped under: (1) biomechanical techniques, (2) physiological techniques, and (3) psychophysical techniques. For each of the techniques, some basic references are provided so the procedural details, which can not be covered in detail in this document due to the need for brevity, may be obtained.

This document is intended for small businesses which have minimal internal resources dedicated to ergonomics. It emphasizes those techniques that are simple and do not require extensive data collection or protracted analysis or experts for interpretation. However, some knowledge in the field of occupational safety and health, or access to individuals with such knowledge, may be helpful in applying/using the following information in their specified work environments.

This document is written in simple language, avoiding the ergonomics jargon. Further, even though several hundred published and unpublished documents were evaluated, only essential references are cited.

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GLOSSARY OF TERMS USED

Abduction - Movement laterally, away from the body centerline.

Adduction - Movement laterally, toward the body centerline.

Asymmetrical Load Handling - Load handling in non-sagittal planes.

Cumulative Trauma Disorders (CTDs) - Physical impairments due to chronic, or accumulative, effects of work-related microtrauma to the musculoskeletal system.

Dynamic Work - Work characterized by a rhythmic alternation of muscular contraction and extension, tension and relaxation.

Grip Strength - The maximum force that can be exerted by a handgrip.

Injury Incidence Rate - Number of cases per 200,000 work hours or per 100 workers.

Isoinertial Strength - Muscular force required to overcome the initial static resistance (external)

Isokinetic Strength - Muscular force when the muscle contracts at a constant velocity.

Job Analysis - The process of finding information about the job and the people performing it.

Joint Extension - Movement at the joint in the sagital plane resulting in larger joint angle.

Joint Flexion - Movement at the joint in the sagittal plane resulting in smaller joint angle.

Maximum Voluntary Contraction (MVC) - Maximum force that can be exerted by voluntary muscular contraction.

Physical Work Capacity (PWC) - Maximum amount of oxygen human body can consume per minute.

Posture - The configuration of the human body in the course of performing an activity.

Power Grip - Grip formed by the thumb and four fingers as a claw (such as when using a hammer).

GLOSSARY (continued)

Pronation - Rotation of the hand about the long axis of the forearm such as to face the palm downward when the forearm is held horizontally forward.

Radial Deviation - Deviating the wrist towards the thumb side (radial bone of the arm/ hand).

Sagittal plane - A plane dividing the body into two halves: left and right.

Static Work - Work characterized by a prolonged state of contraction of the muscles.

Supination - Opposite of pronation - turning palm upward.

Symmetrical Load Handling - Load handling in the sagittal plane.

Therbligs - Basic, or fundamental, motions of the human body that can not be broken down any further.

Ulnar Deviation - Deviating the wrist towards the little finger side (ulna bone side of the arm/hand).

RECOMMENDED READING

1. Dul, J. and Weerdmeester, B. **Ergonomics for beginners: a quick reference guide**. Taylor & Francis, London, United Kingdom, 1993.

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1. INTRODUCTION

Musculoskeletal injuries and disorders in the work place are widespread, affecting thousands of workers in the United States each year. **The two areas of the body that are most frequently involved in occupational injuries are the lower back and the upper extremities (wrists, hands, elbows, and shoulders).** The resulting injuries can often lead to a permanent disability.

Cumulative trauma disorders (CTDs) are physical impairments due to chronic, or accumulative, effects of work-related repetitive microtrauma to the musculoskeletal system. Even though it is generally agreed that cumulative trauma disorders of the upper extremities and the lower back are the most pervasive work-related overexertion injuries, accurate injury and cost data associated with these injuries are difficult to acquire. Between these two kinds of injuries, more accurate data exist on lower back musculoskeletal injuries. Even these data are nearly a decade old.

According to the National Safety Council (1990), 31% of all injuries in the workplace are musculoskeletal overexertion injuries; 22% of all injuries are overexertion injuries of the lower back. The percentage of overexertion injuries in a particular industry may be higher or lower. According to Pizatella et al. (1992), industries with a greater risk of back injuries are general building contracting, heavy construction, trucking and warehousing, pipelines (excluding natural gas), and wholesale trade (durable goods). When back pain is considered, the problem becomes enormous (Deyo, 1988). In fact, as many as a third of the population may be inflicted with back pain at some point in their lifetime (Asfour et al., 1983).

In terms of cost, the published literature does not provide separate costs for back injuries and back pain incidents. According to Holbrook et al. (1984), back pain costs in 1984 were approximately $ 16 billion; lost wages accounted for approximately $ 2.5 billion of this cost. However, according to Frymoyer et al. (1983), the annual lost wages between 1975 and 1978 were of the order of $ 11 billion. Taber, in 1982, reported the estimated annual direct cost of back problems in the United States in 1982 to be $14 billion; however, according to Helms (1985), the cost of surgical back procedures alone exceeds $12 billion annually. The total annual cost, using the health care industry practices to estimate the indirect costs (in the health care industry, the indirect costs are at least 4.5 times the direct costs - Hartunian et al., 1980), would be nearly $77 billion if the annual direct costs were $ 14 billion. Given a conservative annual increase of 8% in the health care costs due to inflation, the total current cost of back problems in the U.S. can be estimated to be approximately $ 210 billion per year. (For additional discussion on injury and cost statistics, readers are referred to Deyo, 1988; Ayoub and Mital, 1989, and Mital et al., 1993a).

While there are data available on the lower back musculoskeletal injuries and disorders from a variety of sources, no matter how contradictory and inaccurate, there is very little cost and injury information available for the upper extremity disorders. According to Putz-Anderson (1988), "The overall prevalence of cumulative trauma disorders (CTDs) is not

known, but data collected at individual worksites suggest that CTDs are responsible for a significant amount of lost work time and high labor turnover". Even the most recent reference on preventing work-related upper extremity musculoskeletal disorders (Kuorinka and Forcier, 1995) states that, "The extent of the problem is not precisely known".

In spite of these admissions, some researchers have provided injury and cost statistics. According to Jensen et al. (1983), motion-related wrist disorders account for 6% of injury cases in 1979. In 1990, 185,400 cases of CTDs were reported in the workplace (Falkenburg and Schultz, 1993); the percentage of carpal tunnel syndrome, an upper extremity CTD, increased from 28% to 48% of all upper extremity CTDs between 1984 and 1988. In some industries, the percentage of workers afflicted with upper extremity CTDs may be as high as 25% (Armstrong et al., 1986). None of these publications, however, provide costs associated with upper extremity CTDs.

In 1987, Aghazadeh and Mital reported injury statistics associated with the use of hand tools. They found that approximately 9% of all injuries were caused by hand tools resulting in a cost of approximately $ 10 billion per year. Overexertion was reported to be the second leading cause of injuries when using non-powered hand tools. Over the last decade, the use of personal computers and key board activated automated equipment has proliferated the work place. Keyboards have been identified as a major cause of upper extremity CTDs (Kilborn, 1994a,b). Therefore, even though we do not have a definite idea of the magnitude of costs, it is logical to expect that costs associated with these musculoskeletal disorders have also increased.

Available information on the incidence of musculoskeletal injuries and disorders indicates that injuries of the lower back and upper extremities are a pervasive and expensive problem in the work place (National Safety Council, 1990; Putz-Anderson, 1988). While injuries directly affect the injured worker, costs reduce the overall industrial productivity by increasing costs for medical care, insurance, recruitment, and training of replacement workers. In addition, there are costs associated with lost business opportunities, production disruptions, poor quality workmanship, lower performance, etc. **It is critical, therefore, to recognize and control musculoskeletal injuries and disorders associated with work.**

The control of musculoskeletal injuries and disorders involves recognizing work and work environment factors that may be contributing to the risks of such injuries. However, before initiating efforts to identify these risk factors, it is advisable to determine where such efforts should be focused. The focus areas may be determined by reviewing employee complaints or analyzing injury data, if such data are available. In the event injury records are available, a thorough review of these records and, if possible, the associated costs, is recommended in order to identify focus areas. From these data, injury incidence rates (number of cases per 200,000 work hours or per 100 workers) should be calculated for:

- each affected job classification,
- each affected work station,
- age group above and below 40 years,
- both genders, and
- all work shifts.

These incidence rates provide:

- An indication about which job classifications and work stations are problems,
- A relative ranking of jobs and work stations in terms of severity,
- A priority list of jobs and/or work stations for hazard recognition efforts,
- An idea about how widespread the musculoskeletal injury/disorder problem really is, and
- An indication if the problem is influenced by age, gender, or shifts.

Once the above information is available, hazard recognition efforts can be focused.

It is possible that the employees currently may not have any musculoskeletal problems or complaints. Nevertheless, it is recommended that a thorough analysis of all the workplaces and jobs be carried out to identify and prevent any potential or future problem. Such a proactive approach establishes a healthy working atmosphere and can result in substantial savings in costs and efforts in the future.

2. OCCUPATIONAL RISK FACTORS ASSOCIATED WITH WORK-RELATED OVEREXERTION MUSCULOSKELETAL INJURIES/DISORDERS

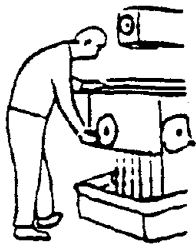
A number of work-related factors have been identified as risk factors that are associated with overexertion musculoskeletal injuries and disorders. For the lower back injuries/ disorders, these risk factors are listed below; some of these factors are also depicted in Figure 1 (For an extensive discussion on these factors, please refer to Mital et al. (1993a):

- Static work
- Posture/technique
- Load characteristics
- Handles/coupling
- Frequency/repetitive handling
- Asymmetrical handling/non-uniform loads
- Space confinement/restraints
- Environment
- Working duration
- Work organization

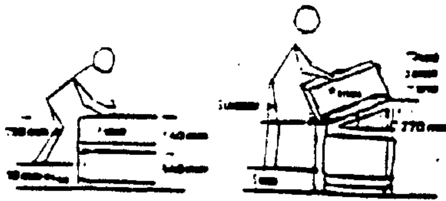
For the upper extremity CTDs, the risk factors are (Figure 2) (For an extensive discussion on these factors, please refer to Kuorinka and Forcier, 1995):

- Fit, reach, and vision
- Cold, vibration, and local mechanical stress (shock, impact, impulsive loading)
- Awkward postures
- Musculoskeletal and mechanical load (force, repetition, duration, load modifiers)
- Static load/work
- Task invariability
- Cognitive demands
- Work organization

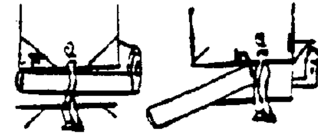
The linkage between these occupational factors and musculoskeletal injuries and disorders in the work place is not always based on direct evidence (cause-effect relationships). In fact, most of the information is epidemiological and circumstantial in nature. In most reported cases, a reference or control population was not available for comparison purposes.



a. Static work

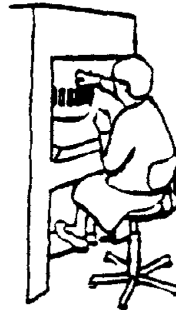


b. Posture/technique



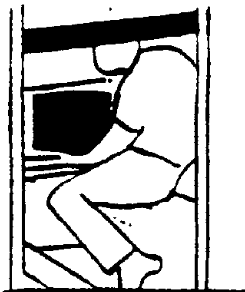
c. Load characteristics

d. Handles/coupling

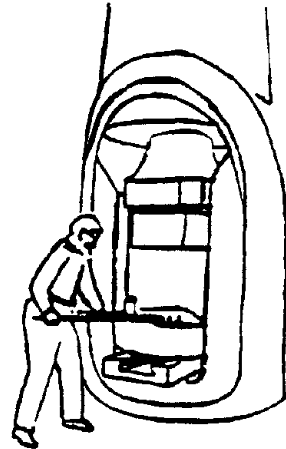


e. Repetitive handling

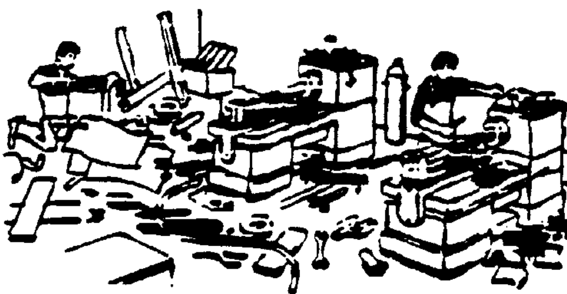
f. Asymmetrical handling

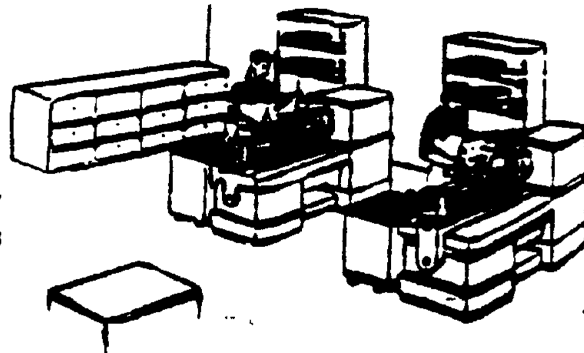


g. Space confinements



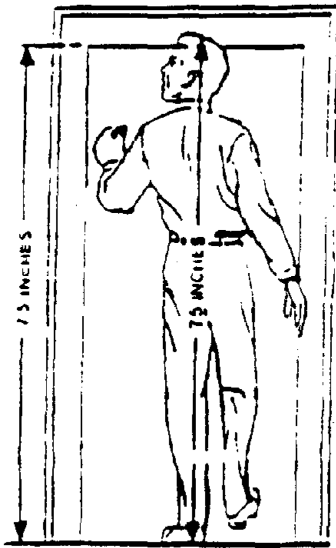
h. Environment



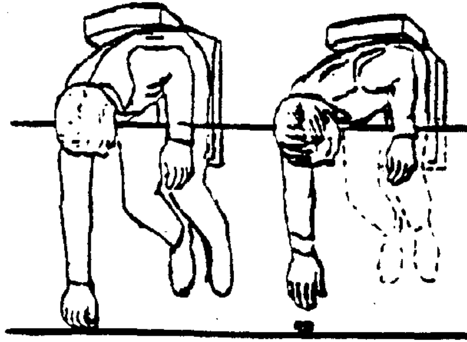


i. Work Organization

Figure 1. Risk Factors Associated With Low-Back Injuries/Disorders (see Appendix for the listing of sources).



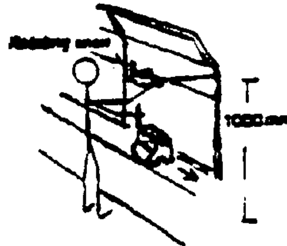
a. Fit



b. Reach

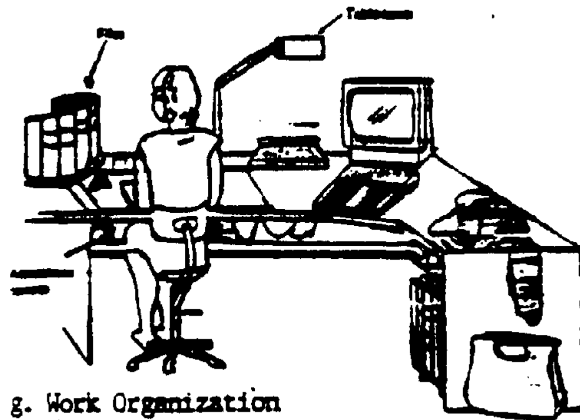
c. Awkward Postures

d. Static load/Work



e. Task invariability

f. Cognitive demands



g. Work Organization

Figure 2. Risk Factors Associated With the Upper Extremity CTDs (see Appendix for the listing of sources).

Nevertheless, there is evidence that work environment and the performance of work contribute to these injuries and disorders (Kuorinka and Forcier, 1995). From a global perspective, the World Health Organization (1985) recognizes work performance and work environment as contributors to musculoskeletal injuries and disorders. Ayoub and Mital (1989) and Mital et al. (1993a) discuss the specific nature of the risks these factors pose for the lower back. For the upper extremities, the evidence is discussed by Putz-Anderson (1988) and Kuorinka and Forcier (1995).

The cause and effect relationships between the various occupational risk factors are summarized in the following subsections.

2.1 OCCUPATIONAL RISK FACTORS ASSOCIATED WITH THE LOWER BACK

A number of work and working environment-related factors have been suggested by various researchers as risk factors in performing manual materials handling (mmh) activities, leading to overexertion musculoskeletal injuries and disorders (Section 2 and Figure 1). This section briefly reviews the outcome of many studies on each of these factors. The information contained in this section is based on extensive reviews of literature provided by Ayoub and Mital (1989) and Mital et al. (1993a).

2.1.1 Static work: Almost all activities involving materials handling contain both the static and the dynamic component. Tasks, such as repetitive lifting tasks, have a dominating dynamic component, while tasks such as load holding have a dominating static component. The static work effort is characterized by contraction of muscles over extended periods of time (e.g., adopting a posture for extended periods of time). **It has been shown that static work endurance is affected by work load and, therefore, static work should be avoided as much as possible.**

2.1.2 Posture/technique: Body posture changes force requirements and may cause work to become very strenuous. Often the activity forces the body to assume different postures. The review of various studies shows that the **stoop posture is advantageous when the load must be lifted repeatedly. The squat posture is desirable when the load can be fitted between the knees and is handled only occasionally. Loads that can not be fitted between the knees and must be lifted repetitively should be handled by two individuals or must be moved with the help of a mechanical equipment.** In general, avoid:

- extreme range of movements
- turning/twisting
- moving loads from the floor
- jerky motions
- fixed postures
- lifting loads to overreach heights
- pulling loads

If possible, load movement should be restricted between knee and shoulder height. Pushing force should be exerted in near erect posture if possible, with handles located at a height of approximately 1 meter.

For heavy and awkward loads, the load should be lifted using the squat posture, the weight of the load should be less than the sum of the capacities of the individuals, and the people engaged in lifting it should be similar in height. Coordination of the activity through counting or some sort of verbal signalling is also highly desirable.

2.1.3 Load characteristics: For greater stability, the load should be:

- rigid and symmetrical in shape
- distributed uniformly
- if non-uniform load, the heavier end should be closer to the body
- load center of gravity offset should be along the line joining the two hands
- the heavier end should be held by the stronger arm

Also:

- the load dimension in the sagittal plane should not exceed 50 cm
- the load dimension between the hands should be minimized
- the load height should be determined by practical considerations such as body size and ability to clearly view obstructions in the path
- the maximum load should not exceed 50 lbs for men and 44 lbs for women.

The limit for men is based on the revised NIOSH lifting guide (NIOSH, 1991); the limit for women is based on Mital et al. (1993a). **It should be kept in mind that these load limits must be revised downwards when other risk factors, such as frequency, awkward object size, and asymmetrical lifting, are present.**

2.1.4 Handles/couplings: Good handles or couplings are essential to provide load and postural stability during materials handling. Cut-out handles should be:

- 115 mm long
- 25-38 mm wide (or diameter, in case cylindrical handles can be provided)
- cylindrical handles should also have a 30-50 mm clearance all round
- handles should have a pivot angle of 70° from the horizontal axis of the box
- handles should be located at diagonally opposite ends to provide both vertical and horizontal stability for the load (Figure 3).

A reduction of up to 15% in the maximum load should be made if the containers or objects being handled do not have handles. In order to prevent slipping while carrying, pushing or pulling, the coefficient of friction between the shoe sole and the floor should be at least 0.3 (preferable value of 0.5). In general, hardened rubber, dense vinyl plastic or leather shoes provide a good coupling.

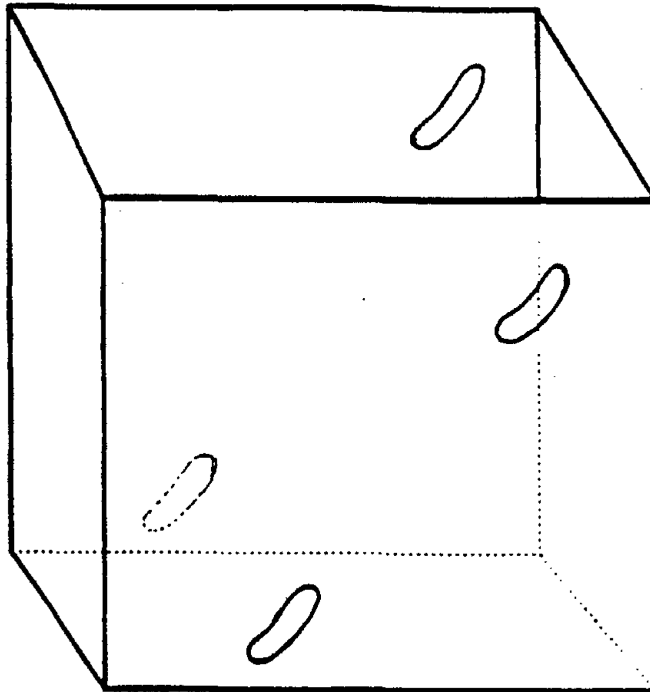


Figure 3. Recommended Location of Handles on objects.

2.1.5 Frequency/repetitive handling: Materials handling activities that require frequent handling should either be redesigned to reduce the frequency or mechanical equipment should be used to aid the handling. The revised NIOSH lifting guide does not recommend load handling frequencies of more than 10/minute if the work is to be done for 8 hours. The handling frequency can increase to 12/minute if the working duration is reduced to 2 hours. Practical considerations, however, may not allow such severe restrictions in the work place. Therefore, an effort should be made to reduce the work load if higher frequencies are encountered. References by Mital et al. (1993a) and Founooni-Fard and Mital (1993 a,b) should be consulted if load handling frequencies higher than 12/minute are essential.

2.1.6 Asymmetrical handling/non-uniform loads: Handling objects asymmetrically is the rule rather than an exception in industrial settings. Asymmetrical materials handling leads to reduced load handling capabilities and strength, increased intra-abdominal and intra-discal (shear) pressures, and increased muscle activity of lower back muscles. **The materials handler is advised not to keep the feet in a locked position. If the feet move the task is less stressful.** The reduction in load lifting capability in such case is expected to be no more than 15% for a 90° turning (For example, if a person can lift 50 lbs straight up, he/she can only lift 35 lbs when turning 90°).

It is also important to realize that since most loads are not symmetrical, **the stronger hand should be closer to the load center of gravity in order to reduce physical stresses on the hands and arms** (please also refer to load characteristics and handles/coupling sub-sections).

2.1.7 Space confinement/restraints: Performing load handling activities with some form of spatial restraint is a common occurrence in industry. **For loads that are to be placed on shelves, the shelf opening clearance for inserting boxes by hands should be approximately 30 mm. If the work place layout does not allow erect posture, e.g. due to limited headroom, the load should be reduced by 1% for each degree of trunk flexion from the erect posture (maximum in the erect posture being 50 lbs for males and 44 lbs for females).**

2.1.8 Environment: Adequate rest and replenishment of body fluids are essential when work is to be performed in hot climates. **Cooling jackets may also be used to keep the core temperature from increasing.**

Protective equipment and clothing (shoes, gloves, vest and trousers, goggles, respirators, aprons and overalls, masks, etc.) should:

- permit free movement
- be easily removable
- allow for personal cooling (protection from body metabolic heat build-up)

and

- gloves should fit
- gloves should allow maintenance of dexterity
- shoes should be non-slip type, comfortable and water proof

2.1.9 Working duration: The work load should be reduced as the working duration increases. The references by Ayoub and Mital (1989), Mital et al. (1993) and the model by Fisher et al. (1993) should be consulted to determine optimal work-rest profiles.

2.1.10 Work organization: Educating employees in safe procedures and **reducing job demands (weight, frequency, reach requirements, rotation and asymmetry) are essential to reduce the hazards of materials handling activities that are performed in work places that do not have adequate space.** Allowing enough room to maneuver in the work place and providing enough space for materials, shelves, tables, etc. are other prime requirements.

Fixed postures should be avoided (see the subsection 2.1 on posture) and the load handling activity should be redesigned to **minimize static work component**; otherwise, **use of mechanical aids should be considered.**

Adequate rest allowances should be provided to overcome the effect of fatigue. The procedure outlined by Ayoub and Mital (1989) should be used for this purpose. **Job rotation should be considered** to minimize monotony, inattentiveness, and fatigue on a specific group of muscles.

While considering job rotation, **attention should be paid to task sequencing**; a physically demanding task should not follow another physically demanding task without adequate rest.

2.2 OCCUPATIONAL RISK FACTORS ASSOCIATED WITH THE UPPER EXTREMITIES

As in the case of the lower back, a number of work-related factors have been identified as occupational risk factors that cause musculoskeletal injuries and disorders in the upper extremities. Tichauer and Gage (1977), Armstrong (1983), Putz-Anderson (1988), Mital and Kilbom (1992a,b), Westgaard et al. (1993), and Kuorinka and Forcier (1995) have listed these factors (Section 2) and also what actions should be taken to eliminate or reduce musculoskeletal injuries and disorders associated with these factors. The problems associated with the upper extremity risk factors and the recommended actions are summarized in this section.

2.2.1 Fit, reach, and vision: The ability of individuals to fit in the work place, to reach objects and hand tools, and see without obstruction can force them to adopt postures and sustain loads that can cause musculoskeletal injuries or aggravate such disorders. **The work place should accommodate large men as well as small women. The work, objects, and tools should be located such that there is no need to lean forward, flex the torso, flex neck/shoulder, or extend arms/hands beyond reach. The work, objects, and tools should also be clearly visible.**

2.2.2 Cold, vibration, and local mechanical stress: Colder working climates have been associated with carpal tunnel syndrome. It is, however, not clear if the occurrence of carpal tunnel syndrome is due to cold temperatures or due to gloves that are worn when working in colder climates. Since cold temperatures reduce blood flow to hands, sensitivity of motor and sensory nerves is reduced. This causes greater exertion of force and increased activation of muscles. The increased activation of muscles is a more likely contributor to carpal tunnel risk than gloves.

Circumstantial and epidemiological evidence indicates that workers who are exposed to hand-arm vibration have a greater risk of injury and musculoskeletal disorders than those who are not. Vibration causes overgripping of the object to maintain control, increased forearm muscle activation and higher muscle loads. In combination with repetitive work, vibration is considered to aggravate musculoskeletal disorders. **In general, it is advisable to avoid segmental vibration (vibration entering the body from the hands) below 1000 Hz. Specifically, hand-arm vibrations in the 2 to 200 Hz range should be avoided** (See Mital and Kilbom, 1992b for a summary. Also refer to NIOSH, 1989.).

Local stresses, such as pressure concentration points resulting from manipulating external objects (e.g. pressure caused by uneven surface projections), can cause injury to nerves, blood vessels, and skin. To avoid these disorders:

- enlarge contact area
- reduce pressure
- avoid leaning against the wrists, hands, and elbows
- minimize impact loads, such as when using hammers, nut drivers, or chain saws

2.2.3 Awkward postures: Extreme postures (postures closer to the end of the joint motion range) can cause:

- extension/flexion and ulnar/radial deviations of the wrists
- flexion/extension and pronation/supination of the elbows
- flexion/extension and abduction/adduction of the shoulders
- flexion/extension of the neck

This could lead to:

- discomfort and joint stresses
- reduced blood flow
- high muscle forces
- fatigue
- reduced endurance (working) time
- acute shoulder and neck pain
- shoulder tendinitis
- carpal tunnel syndrome
- increased sick leave.

The following should be avoided as much as possible:

- hands above the shoulder height
- shoulder elevation
- shoulder abduction of more than 30°
- repetitive shoulder flexion
- overhead reaching
- elbow/forearm pronation
- wrist flexion/extension exposure of more than 20 hours/week
- wrist deviations of more than 20°
- wrist extension/flexion

Also, there is some evidence to suggest that hand manipulations should not exceed 1000/hour for males and 750/hour for females (Fernandez et al., 1995). Furthermore, some researchers suggest that high demands on time (more than 4 hours distributed over the entire day or more than 30 minutes continuously or repetitively) in combination with high force or precision requirements should be considered unacceptable. However, other researchers believe that such

suggestions require more evidence. Wrists should be in the neutral posture (as when shaking hands); slight ulnar deviation ($7° \pm 2$) and wrist extension (up to 20°) may be permitted.

2.2.4 Musculoskeletal and mechanical load: Exertion of force has been associated with musculoskeletal injuries and disorders. While there have been many studies investigating the association between force and musculoskeletal injuries and disorders, only a few have provided a specific value; many have only provided a qualitative assessment of force. From those studies (Putz-Anderson, 1988; Mital and Kilbom, 1992a,b; and Kuorinka and Forcier 1995) that have included quantitative values of force, it has been concluded that the **grip force should not exceed 40-50% of the maximum grip strength. Hand tools should not weigh more than 5 lbs; preferably, the weight should be just under 4 lbs. Pinch type of grips should be avoided when applying force** as it requires up to 5 times more force than a power grip (such as when using a hammer).

The following grip size should be used:

- thickness - 50-60 mm for power
- 8-13 mm for precision
- length - minimum 120 mm for power
- minimum 100 mm for precision, minimum 125 mm with gloves
- guard - minimum 16 mm
- shape - non-cylindrical, preferably triangular with 110 mm periphery
- force - 100 N maximum for power
- handle bent - 10° for power

For details, refer to Mital and Kilbom (1992a,b).

Repetition has been associated with the risk of musculoskeletal injuries and disorders. There is evidence that as few as 7000 hand movements a day could be risky. Other researchers have recommended a higher number (see Mital and Kilbom, 1992b; Kuorinka and Forcier, 1995). **It should be kept in mind that repetition is not present alone in the work place. Usually, repetitive motions involve force exertions and awkward postures. What combinations of these factors are acceptable, is not known.** Further, if two of these three factors are not relevant in a work situation, what values of the remaing risk factor are acceptable is also not very well known (also see subsection on posture).

The duration of work has also been recognized as a risk factor. The demands on time can be divided into three categories:

low (less than 1 hour distributed over the entire day or less than 10 minutes continuously or repetitively)
moderate (1 to 4 hours distributed over the entire day or 10-30 minutes continuously or repetitively), and

high (more than 4 hours over the entire day or more than 30 minutes continuously or repetitively)

High demands in combination with precision or high force requirements should be avoided. If work is performed continuously until exhaustion at 25% of maximum voluntary contraction (maximum volitional strength), recovery does not take place even after 24 hours.

2.2.5 Static load/work: In general, the ergonomics literature recommends avoiding static load and posture. In a static posture or when supporting a static load, the body is unable to meet the metabolic energy requirements (impaired blood circulation) due to a lack of muscle movement. **Static loads and postures also lead to rapid fatigue, pain, impaired nerve conduction, and chronic muscle damage. Postures that are maintained for even as short a duration as 1 minute may be considered fixed.** It should be ascertained that such postural fixity (body in a fixed posture) is not caused by the need to support the equipment, tool, or workpiece.

2.2.6 Task invariability: It has both physiological and psychological connotations. Psychologically, repetitive work leads to monotony and boredom. Physiologically, it could lead to smaller range of motions (postural fixity), pain and discomfort (particularly in torso, legs and feet due to prolonged sitting or standing), and slower movements. Wherever and whenever possible, work should include variety in terms of posture, motions, etc.

2.2.7 Cognitive demands: Mental effort can cause neck muscle tension and stress in general as there is significant need for eye fixation for prolonged periods of time.

2.2.8 Work organization: Please refer to the discussion under risk factors for the lower back. Self-pacing is preferable to machine pacing as it allows workers to control the frequency at which a task is performed without the stress imposed by machine pacing. From a frequency standpoint, **incentive systems such as piece rate systems should not be encouraged. Overtime, particularly unwanted overtime, also has a negative impact on worker health. Night shifts should be immediately followed by days off** as the body needs to recover from the maximum disturbance to the circadian rhythms.

3. ANALYZING JOBS

Before using specific techniques to recognize hazards, it is important to find out as much information about the job and people performing it as possible. This procedure, known as job analysis, can be carried out in two different ways: (1) by conducting a methods study, a popular tool used by industrial engineers and (2) by using checklists. Both methods are briefly described below (For details, please refer to any book on work measurement or motion and time study. Some references are: Konz, 1990; Karger and Hancock, 1982; and Niebel, 1988).

3.1 METHODS STUDY

Methods study is the systematic recording and critical examination of existing ways (proposed ways in case of new jobs) of doing work, as a means of developing and applying safer, easier, and more effective methods and reducing overall costs. It is normally done at two levels:

(1) recording work sequence using a flow process chart and
(2) recording work sequence using the techniques of micromotion study.

The second method of recording work place movements is used for very short cycle jobs and does require filming the job.

The recording of facts about a job using a flow process chart is accomplished with the aid of five symbols:

O (operation), □ (inspection), ⇨ (transport), D (delay), and ∇ (permanent storage)

Combination symbols are also used. For instance O within □ indicates worker performing some operation and inspection.

Once the job details are recorded, the recorded activities must be examined critically (unfortunately, this very important step is not covered in most ergonomics publications). **The questioning sequence should follow a pattern that examines the purpose (for which), the place (at which), the sequence (in which), the person (by whom), and the means (by which) the activities are undertaken with a view to eliminating, combining, rearranging, or simplifying those activities. The idea is to systematically examine every activity recorded for the purpose, place, sequence, person, and means.**
The primary questions are:

what is being done
why is it being done (purpose)
where is it being done (place)
when is it being done (sequence)

who is doing it (person) and
how is it being done (means)

Once these primary questions are answered, the second stage of questioning is undertaken. In this stage, options (what else?) are sought. The questions that are asked are:

what **else** might be done and what else **should** be done (purpose)
where **else** it might be done and where **should** it be done (place)
when **might** it be done and when **should** it be done (sequence)
who **else** might do it and who **should** do it (person), and
how else might it be done and how **should** it be done (means)

The success of methods study depends upon accurately recording and answering these questions.

For jobs that have very short cycle time (typically, in seconds) and which are repeated thousands of times (such as assembly operations), recording greater details is necessary. The job is filmed and subjected to micromotion study. All activities are divided into fundamental motions known as therbligs (there are 18 fundamental motions, but 17 are needed most of the time). This is done by playing and analyzing the film, or videotape, frame-by-frame.

Once the job has been recorded, the contents should be analyzed for risk factors. Checksheets, such as the one shown in Tables 1 and 2, may be used for this purpose.

3.2 CHECKLISTS

As an alternative to methods study, or as a supplement to it, checklists may be used to conduct job analysis. The hazard recognition techniques, described in the next section, should be used in conjunction with checklists to identify risk factors and the extent to which they may potentially contribute to the problem.

The main question is "which checklist should be used?". In fact, a number of checklists have been developed and range from very simple (Dul and Weerdmeester, 1993) to elaborate (Kellerman et al., 1963; International Organisation for Standardization, Geneva, Switzerland). Many companies, depending upon their need, develop their own checklist. Table 1 shows a very general checklist modified from Dul and Weerdmeester (1993) and Kellerman et al. (1963).

A checklist more specific to upper extremities was developed and evaluated by Keyserling et al. (1993) is provided in Table 2.

As these two checklists illustrate, the amount of information provided by a checklist varies considerably and is determined by the nature of questions asked. Considerable attention should be given to developing a checklist. It is better to ask questions which may not appear to be relevant, at least initially and until the checklist is evaluated, than to find out later that relevant information was not included in the checklist. One may begin with the development of an exhaustive checklist and then eliminate questions systematically. At the very least, such an effort will lead to consideration of all the information. One should also realize that gathering information in this manner can be time consuming and expensive as one may end up gathering irrelevant information. An efficient checklist, therefore, is a very important tool. Where exactly the balance between detail and cost/time lies varies from situation-to-situation. One must question the necessity for the level of detail (people love details but are they necessary?) and how it helps in understanding and eventually solving the problem. Once the information has been gathered with the help of the checklist, it should be analyzed for the answers (yes, no, quantitative, etc.) to identify the risk factors, problems, etc. so that appropriate control actions may be initiated.

Table 1: A simple ergonomics checklist for eliminating/reducing musculoskeletal injuries and disorders in the workplace.

1. Has a tall man enough room?	y	n
2. Can a petite women reach everything?	y	n
3. Are excessive reaches avoided?	y	n
4. Is the work within normal reach of arms/legs?	y	n
5. Can the worker sit on a good chair (back, seat, height)?	y	n
6. Is standing alternated with sitting and walking?	y	n
7. Is an armrest necessary? Is it good (adjustable, supports arms without pinching, doesn't restrict movement, etc.)?	y	n
8. Is a footrest required? Is it good (adjustable, supports load, stable, etc.)?	y	n
9. Is it possible to vary the working posture?	y	n
10. Is there enough clearance for knees? feet?	y	n
11. Is the distance between eyes and work correct?	y	n
12. Is the workheight adjustable?	y	n
13. Has the use of platforms been avoided?	y	n
14. Is static work avoided as much as possible?	y	n
15. Are vises, jigs, conveyor belts, etc. used wherever possible?	y	n
16. Where protracted muscle loading is unavoidable, is the static strength required less than 10% of the maximum?	y	n
17. Is the dynamic strength required for protracted work less than 5% of the maximum?	y	n
18. Are power sources employed wherever possible?	y	n
19. Has the number of muscle groups employed minimized with the help of counterbalance?	y	n
20. Are torques around the axis of the body avoided as far as possible?	y	n
21. Is the direction of motion as correct as possible in relation to the amount of force required?	y	n
22. Are loads that are lifted/carried with two hands below 50 lbs for men? Below 44 lbs for women?	y	n
23. Are the joints in a neutral position?	y	n
24. Is the work held close to the body?	y	n
25. Are forward-bending postures avoided?	y	n
26. Are twisted trunk postures avoided?	y	n
27. Are sudden and jerky movements/forces avoided?	y	n
28. Is there a variation in postures and movements?	y	n
29. Is the duration of any continuous muscular effort limited?	y	n
30. Is muscle exhaustion avoided?	y	n
31. Is rest taken after heavy work?	y	n
32. Are breaks sufficiently short to allow them to be distributed over the working duration?	y	n

Table 1: (continued) A simple ergonomics checklist for eliminating/reducing musculoskeletal injuries and disorders in the workplace.

33. Are hand-held tools not too heavy?	y	n
34. Are tools maintained properly?	y	n
35. Is the tool grip of proper size (length, diameter, etc.)?	y	n
36. Has work above the shoulder been avoided?	y	n
37. Has work with hands behind the shoulders been avoided?	y	n

Note: These questions can be expanded and made more specific by including quantitative information discussed under the risk factors and provided elsewhere in major references.

Table 2. Upper extremity checklist (slightly modified from Keyserling et al., 1993).

Worker information

Which hand is the operator's dominant hand? (circle one)	Left hand		Right hand		Bothhands
Circle a, *, ✓ or 0 to answer each question below...					
Repetitiveness			no		yes
1. Does the job involve repetitive use of the hands and wrists? Answer "yes" if either of the following is true a. The work cycle is less than 30 seconds long, or b. The hands repeat the same motions/exertions for more than 1/2 of the work cycle.					
Mechanical stress	**Left hand**		**Right hand**		
2. Do the hand or sharp objects, tools, or part of the workstation put localized pressure on:	no	yes	no	yes	element
a. back or side of the fingers?	0	✓	0	✓	______
b. palm or base of the hand?	0	✓	0	✓	______
c. forearm or elbow?	0	✓	0	✓	______
d. armpit?	0	✓	0	✓	______
3. Is the palm or base of the hand used as a striking tool (like a hammer)?	0	✓	0	✓	______
Force					
4. Does the worker lift, carry, push, or pull objects weighing more than 4.5 kg (10 lbs)?	0	✓	0	✓	______
5. Does the operator grip an object or a tool which has a smooth, slippery surface (no texture or hand holds to reduce slipping)?	0	✓	0	✓	______
6. Is the tip of a finger or thumb used as a pressing or pushing tool?	0	✓	0	✓	______
7. Check box if no gloves are worn and skip this question	☐				
If the operator wears gloves, do the gloves hinder gripping?	0	✓	0	✓	______

Table 2. (continued)

	Left hand			Right hand			
	no	some	more than 1/3 cycle	no	some	more than 1/3 cycle	element
8. Does the operator grip or hold a part or a tool which weighs more than 2.7 kg (6 lbs) per hand?	0	✓	*	0	✓	*	______
Posture							
9. Is a pinch grip used?	0	✓	*	0	✓	*	______
10. Is there wrist deviation?	0	✓	*	0	✓	*	______
11. Is there twisting, rotating, or screwing motion of the forearm?	0	✓	*	0	✓	*	______
12. Is there reaching down and behind the torso?	0	✓	*	0	✓	*	______
13. Is an elbow used at or above mid-torso level?	0	✓	*	0	✓	*	______
Tools, Hand-held objects, and Equipment							
14. Is vibration from the tool or object transmitted to the operator's hand?	0	✓	*	0	✓	*	______
15. Does cold exhaust air blow on the hand or wrist?	0	✓	*	0	✓	*	______
16. Is a finger used in a rapid triggering motion?	0	✓	*	0	✓	*	______

	no	yes	no	yes
17. Is the tool or object unbalanced?	0	✓	0	✓
18. Does the tool or object jerk the hand?	0	✓	0	✓

List all tools, objects, and equipment used to answer Questions 14-18.

Tool Score = (No. of *'s) x (No. of ✓'s) =

Comments:

4. TECHNIQUES TO ASSESS RISK FACTORS

The techniques to assess risk factors associated with musculoskeletal injuries and disorders are broadly classified as:

(1) biomechanical techniques,
(2) physiological techniques, and
(3) psychophysical techniques.

Some of these techniques are quantitative and some provide qualitative information. Following is a brief description of techniques in each of the three categories that can be used for evaluating jobs for risk factors listed in Section 2. For each technique, at least a basic reference is given so that the users may obtain additional procedural details not provided here. Wherever possible, references to equipment and its sources are provided.

4.1 BIOMECHANICAL TECHNIQUES

These techniques focus on assessing forces/stresses and motions that are generated as a result of performing specific activities.

4.1.1 Spinal stresses: Spinal stresses (compressive and shear) provide an indication of the hazard the body is subjected to while handling loads. A number of biomechanical models have been developed to assess these stresses. Some perform static and two-dimensional (2-D) analysis while others perform dynamic and three-dimensional (3-D) analysis. Dynamic three-dimensional biomechanical models are more accurate in comparison to static 2-D or 3-D models. Even though several biomechanical models are available, most are complex and user unfriendly; only a handful can be used by people at large, particularly those in industry. Two such models are briefly described.

However, before these models are used, it is essential to understand the limitations of these and any other existing biomechanical model. Static models consider the motion of the human body as a series of static postures and perform static analysis in each posture to determine musculoskeletal stresses. Dynamic models account for the inertial effects of the body segments and the loading due to acceleration. **Static analyses seriously underestimate the spinal stresses, by as much as 40-50%, as the effect of the inertial forces is neglected. Dynamic models reduce this drawback of static models; however, they introduce complexity in terms of the input data acquisition required.** The process of acquiring input data gets more difficult by the number and the type of input variables required. This is important for the user of the model, especially in field situations. Furthermore, **it should be realized that the utility of biomechanical models is greater for comparative task analysis than for standalone task analysis to determine absolute load values.** Most of these models compare the model generated spinal stresses with the load tolerance capability of the human spine (cadaver spines) to estimate the factor of safety. Since

the human tissue tolerance capability under dynamic conditions is not known, we only get a relative assessment of different tasks and task conditions or an approximate idea of the hazard.

The static biomechanical model (2-D or 3-D) is available from the University of Michigan's Center for Ergonomics for approximately $600 for 2-D version and $1000 for the 3-D version. The models are basically static strength models and predict population capable of performing each task from a variety of inputs: body posture, object, force needed to oppose the object (average, maximum), and location of the hands. The details of the model can be obtained from Chaffin and Andersson (1991). The model is user friendly and can be easily used.

One of the existing 3-D dynamic biomechanical models that is user friendly is available from the University of Cincinnati's Ergonomics and Engineering Controls Research Laboratory. The model is being made available to interested users at the cost of duplication and postage (in 1996, $35). The details of the original model are available in Kromodihardjo and Mital (1986, 1987). The documentation indicating the data input requirements and simplifications made comes with the model. The model can handle both symmetrical and asymmetrical manual lifting tasks and requires minimal input (worker's body size, load, type of task) to determine spinal stresses and the factor of safety.

4.1.2 Risk potential for manual handling activities: The models discussed in the previous section are limited to manual lifting activities that are performed infrequently or occasionally. Most industrial jobs are not pure lifting jobs; they involve a variety of handling activities, such as carrying, pushing, etc., in a variety of combinations. Frequently, it is of interest to find the risk of musculoskeletal injury associated with such task. To date, one model has been developed that can handle analysis of a diverse multiple activity manual handling job. This model has undergone a number of revisions, the latest described by Mital (1995). The documentation of the procedure and the model (written in Basic) are available from the University of Cincinnati's Ergonomics and Engineering Controls Research Laboratory at cost (in 1996, $50). The model is based on the materials handling guide developed by Mital et al. (1993a) and takes into consideration such factors as: worker gender, population percentile, types of task (lifting, lowering, pushing, pulling, and carrying), working duration, load symmetry/asymmetry, symmetrical/asymmetrical handling, handling in hot climate, postural/spatial restraints, and presence/absence of coupling. The risk factor for each manual handling is calculated by comparing actual and recommended work loads. Recommended work loads are based on a combination of biomechanical, epidemiological, physiological, and psychophysical design criteria.

4.1.3 Body strengths: Human strengths are a primary measure of an individual's physical capabilities, particularly those that permit a person to exert force or sustain external loading without inflicting personal injury. As stated under risk factors section, **jobs that are static in nature and are performed for prolonged periods of time (something that should be avoided) should not require more than 10% of a person's maximum voluntary contraction (MVC; strength); some recommendations limit this exertion to no more than 2-3%. For prolonged dynamic tasks, the strength requirements should not exceed 5% of MVC.** The extent of static

or dynamic effort should be compared with MVC to determine how potentially hazardous the job is. The techniques to measure effort on the job are described later in the force subsection.

Static (also known as isometric) strengths are the capabilities of muscles to produce force or torque by a single maximal voluntary exertion such that the length of the muscle remains unchanged (zero displacement). Since the posture assumed by the worker influences strength, it is necessary to specify the posture during strength measurement. Static strength measurement requires that individuals build-up their muscular exertion against a fixed resistance slowly over a 4-6 second period, without jerking, and maintain the peak exertion for about 3 seconds. A rest break of at least 30 seconds is provided between successive exertions; 2 minutes if necessary. No external motivation is provided. The peak strength, thus recorded, is the MVC of the individual. Several different devices are available to record peak static muscular exertion. One popular static strength measuring device (ISTU-Isometric Strength Testing Unit; cost can vary from $2,000 to $25,000^+$, depending upon the attachments) is marketed by Ergometrics, Inc. (Ann Arbor, Michigan). The device allows measurement of push/pull/lift and other types of forces through an adjustable frame. The frame permits adjustments in the horizontal and vertical distances. The device also comes with a personal computer and data analysis software. A similar device is available from Lafayette Instrument of Lafayette, Indiana (the Jackson Strength Evaluation System; approximate cost is $3,000). It is less expensive, but limited in terms of the number of applications.

Several different kinds of dynamic strengths have been defined in the literature. The two strengths that are most relevant are isokinetic strength and isoinertial strength. Isokinetic strength is the measure of MVC when the involved body segments move at a constant speed. Speed control is achieved by a mechanical or hydraulic device that does not allow the body segment to move faster than the pre-selected speed, the prime requirement of isokinetic strength measurement. The worker is asked to assume the required posture, including arm reach distance and arm orientation. Once the worker is ready, he/she is required to exert (pull) the handle to exert as much force as possible, without jerking. The speed of exertion is set such that it simulates the speed of the task. The maximum force of exertion is recorded. Rest breaks between successive exertions must be provided and the posture, speed of exertion, arm orientation, reach distance, and population must be reported with the data. A Super II Mini-Gym, build by Fitness Systems, Inc., located in Independence, Missouri, may be used for measuring isokinetic strengths. It costs approximately $300. Alternative equipment is available from CYBEX, Bay Shore, New York, at a substantially higher cost ($30,000^+$).

Isoinertial strength measures the ability of a person to overcome the initial static resistance by measuring the maximum amount of weight he or she can handle and move to an assigned point at a freely chosen speed. Actual speed of movement varies within the specified range of movement. Maximum weight can be determined by incrementing weights (as high as 25 lbs or as small as 2.5 lbs). Initial increments are large (maximum) and if the effort fails, the increment is reduced by half. It should be noted that this strength is not MVC and can be measured with the help of a container and graduated loads. Furthermore, the technique has the disadvantage of risk-exposure, particularly in the upper reach regions where the human strengths are much lower

compared to strengths at lower heights (mid-body region or lower). It is, therefore, likely that the pain tolerance may not be distinguished from trauma.

The details of strength testing are given by Chaffin (1975), Mital and Das (1987), and Mital et al. (1993b).

4.1.4 Videotaping: Videotapes are ideal for recording operators' methods and elapsed time. A careful analysis of tapes provides a wealth of information about several risk factors through micromotion study including posture, cycle time, frequency, and accelerations. From these data, information about forces, joint angles, etc., can be obtained. Since a videotape can provide exact details of the method used by employing real-time speed or frame-by-frame projection, the amount of time different activities take, as well as what improvements need to be made in the job and work place, it is worthwhile to spend money on a sophisticated system. A good videotaping system can cost nearly $10,000 and, besides the camera, includes at least a monitor, a videotape player, and an editor. The complete system can be obtained from a variety of sources including manufacturers of such equipment. The following are the basic requirements of a good videotaping system:

1. Super VHS or 8 mm tape with ability to control shaking during filming,
2. A fast lens (at least f/1.2) with low light recording capability (as low as 3 lux),
3. Ability for wideangle and telephoto zooming,
4. Ability to record at a speed of at least 120 Hz (125 Hz recording speed has been determined to be good),
5. Light in weight,
6. Ability to review records quickly (last few seconds),
7. An FM sound recording,
8. Ability to freeze frames and advance them one at a time, and
9. If possible, two cameras to simultaneously record the activity from two different angles for the purpose of obtaining clear and detailed views.

Other features, such as automatic iris control, are standard on modern video cameras. At least 5 cycles of the task should be filmed. If possible, the job and the operator should be filmed from the front, both sides, rear, and at an angle from the front-above (3/4th exposure above the operator's head height). Once the job has been videotaped, the tape can be played back for micromotion analysis and recording of risk factors. As stated earlier, any standard text on motion and time study provides details of micromotion analysis procedures (i.e., Niebel, 1988). The procedure involves breaking the job cycle into basic motion elements described by therbligs. The number of frames an activity takes and the speed of videotaping provide the time the activity takes. The tape can also be used to provide body and body segment angles (multiple views are needed for this) and body joint accelerations (some calculations are needed and are described under the force subsection).

4.1.5 Posture: Posture is the configuration the human body assumes during the course of an activity. Usually, it is necessary to record postures in a 3-D configuration. The simplest form of posture recording can be made through photographs. Typically, the worker would have a grid pattern (ex., one inch squares) as the background. This grid can be used to assess joint and limb angles and reach distances in the plane of interest. However, the body joints must be clearly marked. Joint and limb angles in the vertical and horizontal planes can also be measured using a variety of goniometers (for fingers, limbs, etc.). The posture can be graphically depicted if the limb and joint angles and limb lengths are recorded. The posture, thus recorded, is not very accurate but suffices for practical purposes.

There are several other methods that record the posture by recording its deviation from some basic postures. One of the popular methods is posture targeting (Corlett et al., 1979). The procedure makes use of a diagram (Figure 4), which has "targets" located alongside each of the major limb segments, and on the head and trunk. Marking the form requires the user to take the posture shown in Figure 4 as the zero position. Forward movements by limbs, trunk or head (in the forward-backward plane) require a mark along the vertical axis of the target ("up" for forward) and positioning on that axis according to the estimated angle of displacement. Each concentric circle represents a 45° angle. Displacements to the side of the body are marked on the horizontal axis according to the estimated angle. Directions in a horizontal plane are marked along the appropriate radius or between appropriate radii.

Another method is the "Penguin" method developed by (Kroemer, 1991). It encompasses major body segments (Figure 5) and can be enhanced to include fingers and head. For each segment, a number of preselected positions are shown (more variations of these positions can be included). The observer marks the penguin that most closely resembles the actual working posture. A computer program is available from the developer and provides angles, curvatures, and directions associated with the selected posture.

There are many other methods available to record posture. Many commercial systems have also been developed. While most of the other methods are time consuming, laborious, and inefficient, commercially available systems are expensive, particularly if dynamic postures are to be recorded. For most practical purposes, such methods and systems are not necessary and static posture recording techniques described above are sufficient.

In addition to the techniques described above, joint angles (and hence postures) can be measured by a goniometer. A variety of goniometers are available for measuring finger and other body segment flexion/extension, and include the mechanical analog and digital types. Most of these goniometers can be obtained from Lafayette Instrument (Lafayette, Indiana) for under $500.

For a comparison of some of the posture recording techniques, the reader is referred to the review provided by Punnett and Keyserling (1987).

4.1.6 Body size measurements: Linear body dimensions, such as limb lengths and stature, are needed to determine the worker fit in the workplace. Such measurements and others like reach, can be made by using anthropometers and anthropometric tape. The use of these devices is straight forward. The equipment (anthropometer) can be obtained either from Pfister Import-Export Inc., Carlstadt, New Jersey (Harpenden Anthropometer) for about $1,500 or Lafayette Instrument (Lafayette, Indiana) for about $500. For a description of some standard measurements, the reader is referred to Roebuck (1995) and Pheasant (1995).

4.1.7 Force: Force exerted on workpieces, tools, and other objects in the workplace can be measured in several different ways. The simplest way is to have the operator exert force equivalent to that exerted during his/her job performance on a force transducer (dynamometer). Such methods are reasonably reliable, accurate, quick, simple, and inexpensive. A variety of force measuring transducers/dynamometers is available from Lafayette Instrument for under $500 each and are capable of measuring force exerted by body limbs (hand, arm, finger, feet, whole body) in different postures and grips.

The second method, not mentioned in ergonomics literature, involves the determination of limb acceleration followed by computation of the force by multiplying the acceleration by the mass of the limb or object. Numerical differentiation of displacement data obtained from videotape recording is needed to do this. The technique is described in some detail below.

The object, or joint, where force needs to be measured should be marked prominently (either at the center or at the edge). This mark is videotaped while in motion. The actual distance between the starting and ending points is also recorded. This actual distance and the distance between the same two points when seen on a monitor (film distance) are used to establish the scaling (size) factor (scaling factor S=actual distance between starting and ending points/distance between the same points as measured on the monitor screen). Since the speed of the videotape is known, the time elapsed between successive frames is also known (1/film speed; for 120 Hz speed, time elapsed between successive frames, h, is 1/120 second; note that the system has only 1 image per frame - in the event it has 2 images per frame, time per image will be 1/120 second). The videotape is advanced one frame (image) at a time and the screen displacement of the mark from the starting position is recorded. This displacement is multiplied by the scaling factor to obtain the actual displacement. The displacement associated with the first frame (image) is y_1 and with the nth frame (image), y_n; n is the number of frames (images) required from the starting point to the ending point. From these y_i values (i=1 to n), velocity V and acceleration A for the ith frame (image) are calculated as follows (forward difference method):

$$V_i=(-y_{i+2} + 4y_{i+1} - 3y_i)/2h \quad ; \quad A_i=(-V_{i+2} + 4V_{i+1} - 3V_i)/2h$$

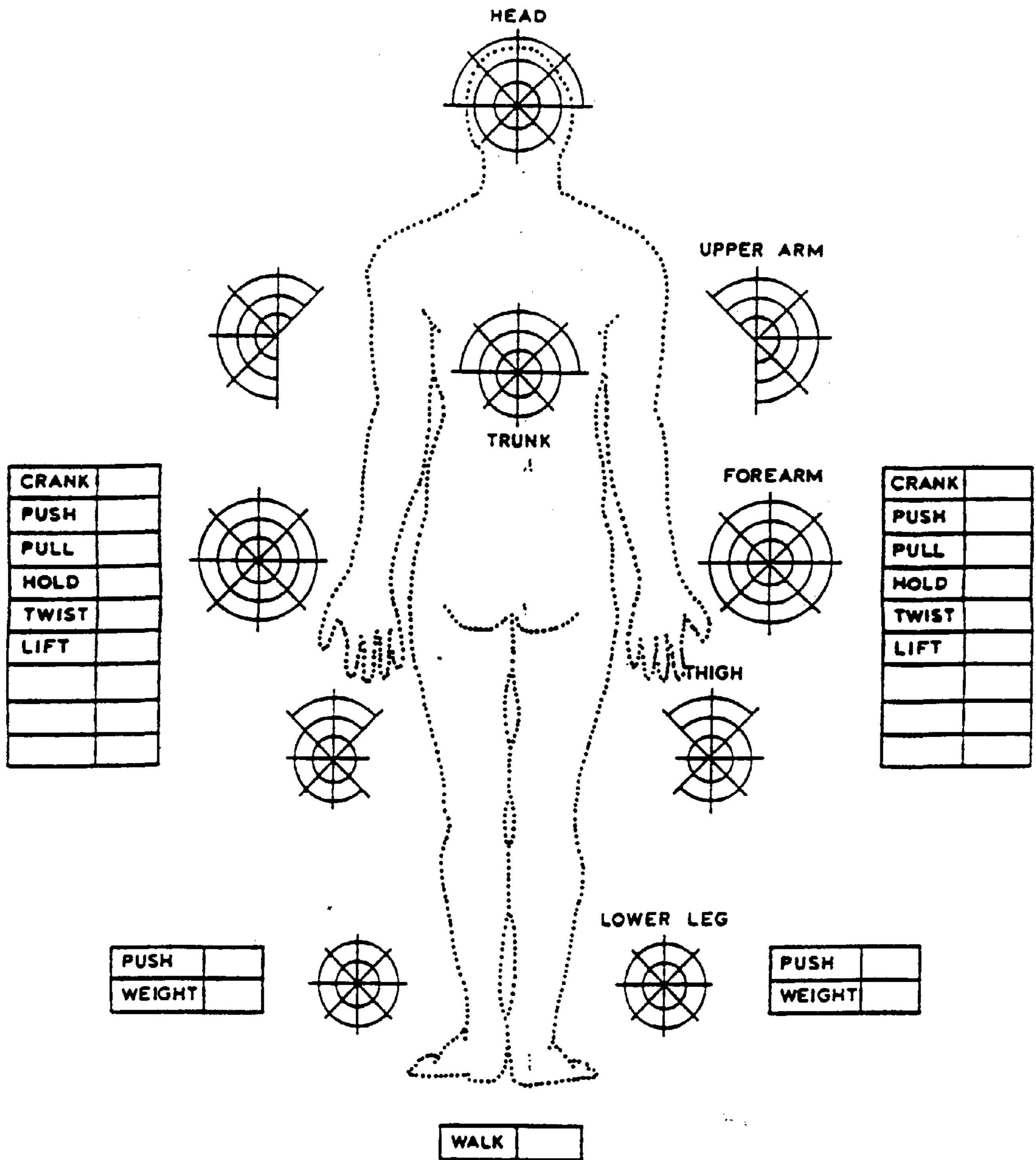
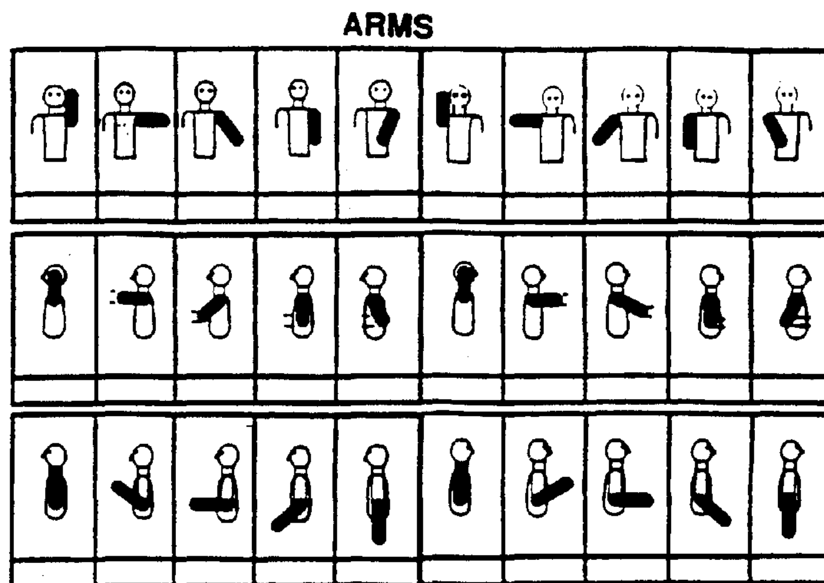
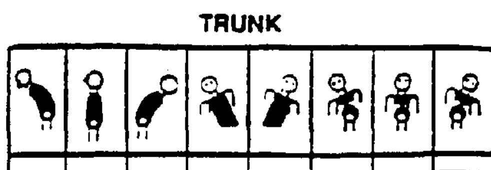
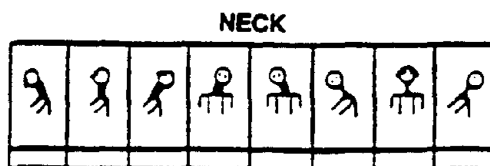


Figure 4. Posture targets with zero position shown by the dotted line (Corlett et al. 1979).







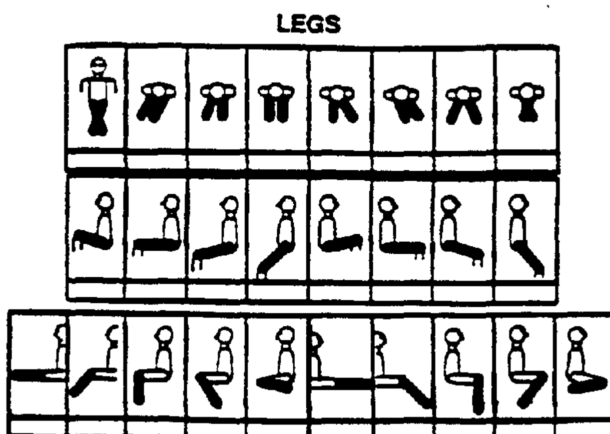


Figure 5. Penguin pictograms of body posture (Kroemer, 1991).

Note that when i=(n-1) or n, data for (i+1)th and/or (i+2)th frames will not be available. These frames can either be ignored or a backward difference method can be used. Since we generally are interested in finding peak forces, peak accelerations are of interest. In most cases, peak accelerations take place somewhere between the starting and ending points and the loss of this information, if the last 2 frames (images) are ignored, is not significant.

Once the acceleration values are computed, one may want to average them, provided it can be ascertained that acceleration during the motion remains constant (ex., when motion is due to gravity); averaging, otherwise, will cause error. Further, it should be noted that errors made in computing displacement are magnified several times due to numerical differentiation. Great care, therefore, should be exercised in recording displacement data. The acceleration data now can be multiplied by mass to obtain force. If the object is external, it can be weighed. For limbs, mass data are provided by Roebuck et al. (1975), Roebuck (1995), and Pheasant (1995).

The third method for measuring force, electromyography, is most commonly recommended in ergonomics literature and is least suitable for industrial application. It is a research tool suitable for use by well trained individuals and is not recommended for industrial users. Further, in many situations it is not appropriate to even use surface electrodes. However, since the technique has been mentioned frequently in the ergonomics literature, it is described here briefly.

When muscles contract, myoelectric signals occur. Electromyography (EMG) is the recording and analysis of these signals. EMG can be used to assess the level of muscular activity as well as to evaluate work and performance. Generally, EMG is best suited for non-repetitive work where the activity of specific muscles is of interest. The EMG signal can provide 4 kinds of information (NIOSH, 1992):

1. Knowledge whether a muscle was in use during an activity or not,
2. Relative level of muscle activity, providing exertion (effort) level (not force),
3. Force generated by the muscle under static or constant velocity, and
4. Muscle fatigue as indicated by the shift of frequency spectrum to lower levels.

However, there are primarily two kinds of EMG analysis that may be of interest in industry: amplitude analysis and frequency analysis. Amplitude analysis provides a measure of muscle activity for different tasks and individuals, while frequency analysis provides an evaluation of the fatigue state of the muscle. In both cases, the EMG signal must be normalized with respect to a reference isometric MVC, and expressed as a % of the maximum voluntary contraction (MVC) as follows:

Relative muscle activity={(task EMG-resting EMG)/(Maximum EMG-resting EMG)}

Such normalization permits comparison across different tasks and people. Whenever possible, the MVC of the muscle of interest should be recorded in a position simulating the actual task position. Subtraction of resting muscle EMG from both activity and MVC provides a measure of task specific muscle activity.

For muscle fatigue investigations, the frequency spectrum needs to be normalized. Since during fatigue the frequency spectrum shifts downwards, normalization is performed over the lower frequency ranges. The amount of frequency signal in a specific range during the state of fatigue is divided by the amount of frequency signal in that range during the beginning of the activity.

Even though three different kinds of electrodes are available (surface, pin, and wire), surface electrodes are adequatefor industrial activities. In most situations, surface electrodes are used in pairs with a third one for ground. Two kinds of surface electrodes are commonly used: dry or active electrodes, which do not require skin preparation, and passive electrodes, which require cleaning of the electrodes, application of a saline gel between the electrode and skin, and skin preparation (cleaning and light abrasion of the skin at the electrode application site). Active electrodes are preferable since they are not only convenient to use but provide relatively greater signal fidelity (accurate transmission).

Once the electrodes are prepared, the application location must be selected. The location chosen should yield the highest signal amplitude. Generally, the electrode should be located in the region halfway between the center of the innervation zone and further tendon. For analysis and interpretation, the electrode signal needs to be amplified by preamplifiers and main amplifiers, filtered, and conditioned, depending upon the need (force information, frequency information, etc.). For further information on this technique, refer to NIOSH (1992) and Basmajian and DeLuca (1985).

As evident from the preceding discussion, considerable preparation and expertise are needed for electromyography. For this reason, its use by non-experts is not recommended.

EMG recording equipment can be obtained from a variety of medical equipment manufacturers. The basic set consists of electrodes, preamplifiers, amplifiers, filters, oscilloscope, analog-digital converters, and computers for data processing and analysis. Among the many manufacturers are Lafayette Instrument, Narco Bio-Systems (Houston, Texas), and Therapeutics Limited (Iowa City, Iowa). Equipment is also available to record EMG through telemetry (Transkinetics Systems, Inc., Canton, Massachusetts). The cost of the equipment generally varies from $10,000 to $30,000 depending upon the number of channels, quality of amplifiers, etc. Simpler and much more economical (2 channel) EMG equipment is available for $2,000 from Thought Technology, Inc. (West Chazy, New York).

4.1.8 Vibration: Basically, vibration of man is measured in acceleration units m/s^2 r.m.s. of a 1/3 octave frequency band (or possibly 1 octave bands for hand-arm vibration) over the frequency range of interest. The level of vibration may also be quoted in logarithmic units in terms of dB re 1 $\mu m/s^2$. Vibration is more critical for upper extremity musculoskeletal injuries and disorders and, therefore, in this subsection the focus will be on hand-arm vibration.

The usual equipment for measuring vibration amplitude is piezoelectric accelerometers which can measure frequencies within the range of 1 to 50,000 Hz. When the accelerometer is exposed to vibration, it moves the stylus against a crystal element which produces an electrical voltage proportional to the compression of the stylus against the crystal element. This voltage is proportional to the acceleration. A charge amplifier is used to make up for any signal loss.

It is important to indicate whether the vibration is being measured on an impact (chain saw, grinders, pneumatic wrenches, etc.) or nonimpact-type tool (chipping hammers, jack hammers, etc.). Shock accelerometers, that have a special filters to attenuate impulse vibration signals, should be used to measure vibration amplitudes of nonimpact type tools.

Many commercially available accelerometers are available and weigh as little as 5 gm. A typical Bruel & Kjaer accelerometer may weigh about 40 gm. The selection of an accelerometer should be done carefully, with consideration given to low amplitudes. The vibration measurements must be made in three independent axes at 90° to each other (orthogonal axes). A triaxial accelerometer, which measures vibration in 3 axes, can also be used instead of three accelerometers. NIOSH (1989) provides some recommendations for mounting locations. Generally, the accelerometers should be mounted to the surface where the maximum vibration energy enters the hand. For assessing vibration exposure to hand, the largest of the rms acceleration amplitudes along the three orthogonal axes may be used. The vibration exposure should also be characterized by the duration of exposure and kind of coupling between the tool and the hand (tight or loose). The guidelines for vibration assessment are based on time-averaged, frequency-weighted rms acceleration levels.

The cost of an accelerometer can vary considerably, from less than $100 to several thousand dollars, depending upon its sensitivity and weight. Therefore, careful consideration should be given to choosing an accelerometer. Some companies provide a vibration measuring kit with their sound level meters (Bruel & Kjaer Instruments, Inc., Marlborough, Massachusetts; Lucas Industrial Instruments, Severna, Maryland). The most economical of these is CEL-3025 vibration attachment that goes with CEL-275 Precision Impulse Integrating Sound Level Meter ($3,200).

4.2 PHYSIOLOGICAL TECHNIQUES

Physiological techniques are suitable for repetitive and whole body work such as manual materials handling. The two human body responses that indicate the extent of hazard and respond to various risk factors given in Section 2 are oxygen consumption and heart rate. The following subsections describe how each can be measured and how each is related to risk.

4.2.1 Oxygen consumption: Oxygen consumed by an individual is influenced by the intensity of the task he/she performs. Typically, oxygen consumption is compared with the physical work capacity (PWC; also known as aerobic capacity, maximum aerobic power, and maximum oxygen uptake - Vo_2 Max). PWC is the maximum amount of oxygen that an individual can consume per minute (maximum oxygen uptake/minute). The higher the percentage of PWC a task requires, the higher the resulting physical stress, fatigue, and possibility of injury.

PWC can be measured by maximal or submaximal methods (Astrand and Rodhal, 1986). In the maximal method, the worker is stressed to the maximum and oxygen consumption at that level is recorded. This method is not recommended for industrial practitioners and, therefore, is not described here. In submaximal methods, individuals are required to perform at least three workloads on either a bicycle ergometer or a treadmill. Even though some researchers have recommended the use of a bicycle ergometer in measuring maximal aerobic capacity, the use of a treadmill is recommended here for two reasons: (1) walking/running is a whole body exercise which avoids localized fatigue in lower legs caused by bicycling and (2) walking/running provides a more accurate estimate of the absolute maximal aerobic capacity than any other method (Sharp et al., 1988; a 10° slope is recommended). At each workload (e.g., 3 mph, 4 mph, and 5 mph), heart rate and oxygen consumption are required to stabilize before they are measured. The individual begins with the lightest workload (walking at 3 mph for instance) and performs at that level until steady state heart rate and oxygen uptake values are reached (it usually takes 3-4 minutes to reach steady state). These values are recorded. Once the measurements are recorded, the workload is increased to the next higher level (e.g., 4 mph). The procedure is repeated until steady state heart rate and oxygen uptake values at all three workloads are recorded. The recorded heart rate and oxygen consumption values are plotted on an x-y graph (e.g., heart rate on x-axis and oxygen uptake on y-axis) and a straight line is drawn through the plotted points. Next the value of maximum heart rate for the individual is determined and plotted on the x-axis. There are several formulas that provide the value of an individual's maximum heart rate. The most accurate of these formulas is:

Maximum heart rate = 214 - 0.71 x Age in years

A vertical line is projected from the maximum heart rate point. A horizontal line is projected from the point of intersection between this vertical line and the straight line

joining the three plotted points. The value given by the intersection of the horizontal line and the y-axis is the PWC of the individual.

When the PWC thus determined is compared with the steady state oxygen consumption of a worker on a job, an indication of the physical stress of the job is obtained. If a job requires more than 21%-23% of PWC for 8-hour shifts, it is very likely to lead to overexertion and, eventually, musculoskeletal problems (Mital et al., 1993a).

The oxygen consumption can be measured by several commercially available devices. Among the ones recommended are MRM-1 Oxygen Consumption Computer (Waters Instruments, Inc., Rochester, Minnesota; approximately $10,000) and Morgan Oxylog (Ambulatory Monitoring, Inc., Ardsley, New York; approximately $10,000). Other devices, such as Beckman's Metabolic Measurement Cart (MMC) are considerably more expensive; MMC costs over $50,000. A telemetry system (K2 System) is also available from Vacumed (Ventura, California) for approximately $150,000.

All of these devices require the worker to put on a mask, breath room air, and exhale into the mask. The exhaled air is analyzed for oxygen content and compared with oxygen content in the room air to determine average minute oxygen uptake.

4.2.2 Heart rate: When humans engage in work, their cardiovascular system is strained. Heart rate, a frequently measured indicator of physical stress to which the individual is subjected, can be measured directly or indirectly (telemetry). The simplest direct method is to take the pulse once the steady state has been reached. The pulse rate should be recorded for a full minute to avoid the effect of sinus arrhythmia. If the pulse rate is being recorded at the end of the work period, a 15 second sample is sufficient; samples of longer duration tend to project into the recovery period. A 3-minute average at the steady state should be recorded. The maximum working heart rate should not exceed 130 beats/minute.

The other method for recording heart rate is somewhat similar to recording EMG in that active and passive electrodes are used. Two electrodes need to be placed on the rib cage, fairly far apart; the ground is placed on a bony landmark. The skin is lightly abraded if passive electrodes are used; such electrodes are covered with an adhesive collar filled with electrode cream.

Heart rate recording devices vary from simple and inexpensive (less than $600), such as Polar and Quinton Heart Rate Meters -- which only provide rate -- to physiographs and datagraphs, which can be used to record electrocardiogram (ECG). The devices that record ECG can cost more than $15,000 and are not really necessary for industrial use. A number of companies provide devices for recording heart rate, including Lafayette Instrument, Quinton (Seattle, Washington; approximately $600), Narco Bio Systems, and Beckman (Schiller Park, Illinois). Polar Heart Rate Meters can be purchased for approximately $ 120 in one of the places that sells exercise equipment.

4.3 PSYCHOPHYSICAL TECHNIQUES

Psychophysical techniques are suitable for repetitive as well as non-repetitive (infrequently performed) tasks. These techniques are also inexpensive as there is little or no equipment needed. The techniques described in this section can be used for the lower back as well as the upper extremities, and include measurement of postural discomfort, static and dynamic work (perceived exertion), and fatigue.

4.3.1 Postural discomfort: Extreme postures or postures that are maintained for prolonged periods of time can be uncomfortable, leading to fatigue and pain. It has been determined that the level of discomfort is linearly related to the force exertion time. Maintaining the same posture is physiologically equivalent to applying a force. A body map and a 5-point scale are used to determine the body part discomfort (Corlett and Bishop, 1976). Figure 6 shows both the body map and the scale. The worker experiencing discomfort in the task being investigated specifies the location of discomfort on the chart and rates it using the scale. The worker rates body parts at regular intervals ranging from 30 minutes to 3 hours. It is also advisable to rate the discomfort just before a break. This method is easy to use and reliable results can be obtained.

General comfort rating scale shown in Figure 7 is another subjective method to assess overall discomfort (Shackel et al., 1979). Initially developed to assess chair comfort, as a significant part of industrial work is done by seated workers, the scale has been found to be reliable for assessing overall body discomfort in a variety of industrial situations.

4.3.2 Rating of perceived exertion (RPE): There is a curvilinear relationship between the intensity of a range of stimuli and workers' perception of their intensity. These perceived exertions can be rated on a Borg Scale (Borg, 1985) shown in Figure 8a. The scale steps (6-20) are linearly related to heart rate (heart rate=10*RPE Scale rating). The scale is presented to the worker before the beginning of work and endpoints (6,20) are thoroughly defined. The scale is then shown to the worker at the end of work and he/she is asked to rate the exertion. A rating of 12-13 is desirable as the maximum work intensity that can be sustained without perceived overexertion.

It should be noted that these ratings are influenced by, in addition to the overall perception of exertion, previous experience and motivation. In general, highly motivated subjects tend to underestimate their exertion.

Figure 8b shows Borg's rating scale with ratio properties to make interindividual comparisons in physical effort ratings (forces/MVC; Borg, 1980). This scale is valid only for large muscle groups and should not be used for work performed by fingers and hands.

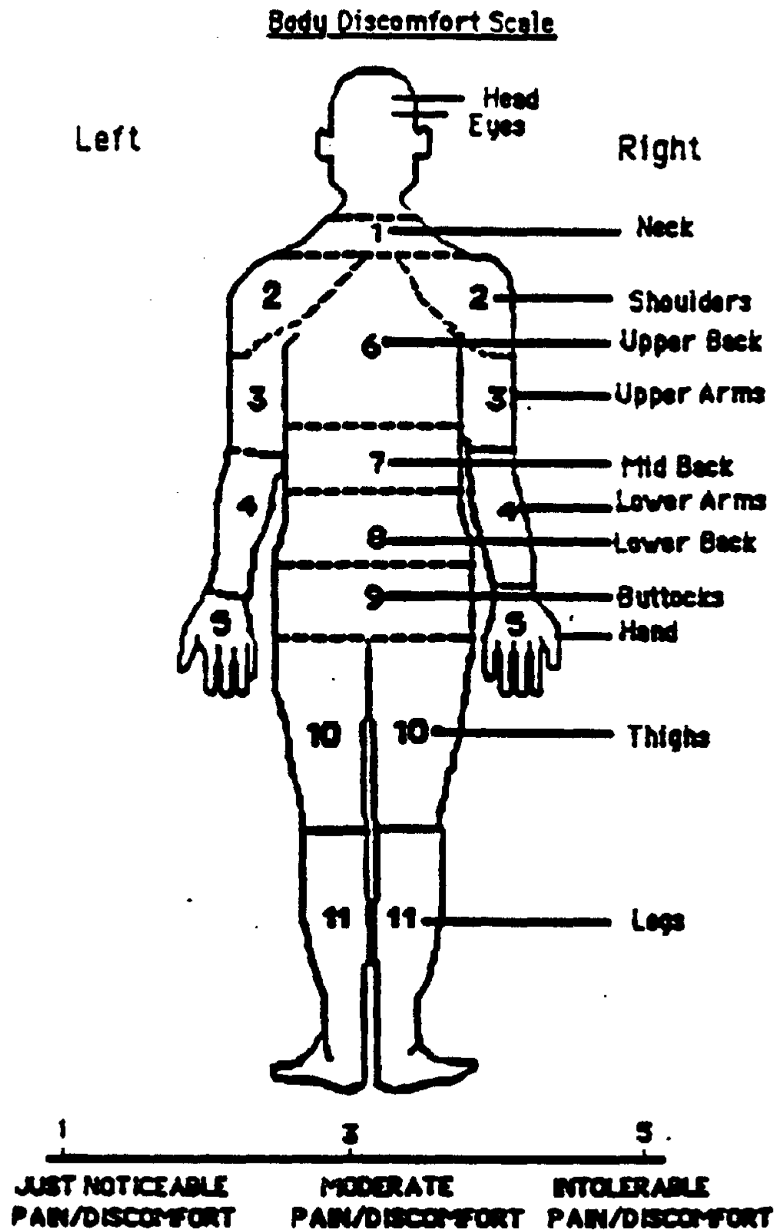


Figure 6. Body part discomfort form and rating scale (Corlett and Bishop, 1976).

Please rate the chair on your feeling *now*.

____________I feel completely relaxed

____________I feel perfectly comfortable

____________I feel quite comfortable

____________I feel barely comfortable

____________I feel uncomfortable

____________I feel restless and fidgety

____________I feel cramped

____________I feel stiff

____________I feel numb (or pins and needles)

____________I feel sore and tender

____________I feel unbearable pain

Figure 7. General comfort rating scale (Shackel et al., 1979).

6	NO EXERTION AT ALL
7	
	EXTREMELY LIGHT
8	
9	VERY LIGHT
10	
11	VERY LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD (HEAVY)
16	
17	VERY HARD
18	
19	EXTREMELY HARD
20	MAXIMAL EXERTION

Figure 8a. Borg's rating of perceived exertion (RPE) scale (physical tasks).

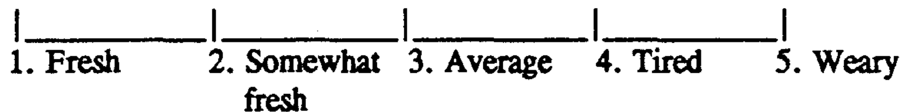
0	NOTHING AT ALL
0.5	EXTREMELY WEAK
1	VERY WEAK
2	WEAK
3	MODERATE
4	SOMEWHAT STRONG
5	STRONG (HEAVY)
6	
7	VERY STRONG
8	
9	
10	EXTREMELY STRONG (ALMOST MAX)
*	

Figure 8b. Borg's rating of perceived exertion (RPE) scale for large muscles.

4.3.3 Other rating scales: A number of other rating scales are available and can be used to elicit information about the job and workplace. One of the techniques employs sharp contrasting pairs of characteristics that give an indication of overexertion or fatigue. The characteristics are:

Fresh	____________	Weary
Sleepy	____________	Wideawake
Vigorous	____________	Exhausted
Weak	____________	Strong
Energetic	____________	Apathetic
Dull, indifferent	____________	Ready for Action
Interested	____________	Bored
Attentive	____________	Absent-minded

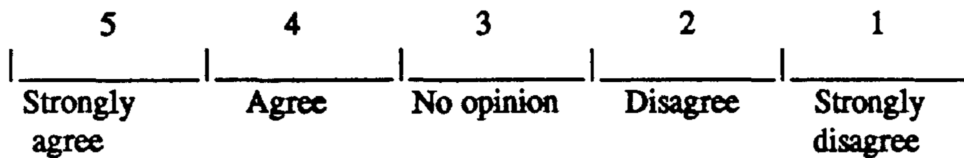
A 3-, 5-, 7-, or 9-point scale can be used to elicit workers' opinions. An example of a 5-point scale would be a response to a question such as "How do you feel?" at the end of a work period:



In the above scale, each point has a value (1 to 5) depending upon which point is selected. The points for different questions can be added to determine worker's opinion.

A variation in rating technique is represented by Likert's Summated Rating Scale. It is a 5-point scale with which a statement is associated (a number of statements, typically 10-20, are used). An example of this scale is as follows:

Statement: "Postural problems are the most serious problems in most of these jobs".



As in the case above, each scale has a point value (1 to 5). Scores for all statements are added to determine worker's opinion. Similar statements are expected to provide similar scores.

There are many other subjective rating methods, perhaps less easy to use, that are available in the published literature. For a review, refer to Sinclair (1995).

5. SUMMARY

The objective of this monograph is to provide relatively inexpensive techniques to evaluate and quantify risk factors associated with lower back and upper extremity musculoskeletal injuries and disorders. The intended users are industries with less than 100 workers which are without any internal ergonomics resources. The techniques that have been described are those that can be used with little training and require equipment which is relatively inexpensive. Throughout the discussion, references to equipment and procurement sources have been provided. For each technique, additional references are given so that the user may obtain detailed information about the technique if desired.

In addition to describing hazard recognition techniques, the monograph also briefly discusses the measures one can take to eliminate or minimize the risks of injury. The sources of this information have also been provided. Emphasis has been on those references that are essential. A detailed ergonomics bibliography (1995) has also been developed by NIOSH and is available from NIOSH (Taft Laboratories, 4676 Columbia Parkway, Cincinnati, Ohio 45226).

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7. APPENDIX

Sources for Figures 1 and 2

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