is not known and cause of pain cannot be prescribed to a specific anatomical structure such as a tendon.

The spinal column and associated intervertebral discs appear to be particularly vulnerable to acute and chronic injury, perhaps because we don't readily sense the extremely high mechanical stresses on the column until the discs have already failed (i.e., after the disc outer fibers have torn and inflammation develops). In such cases, the individual may not just develop low back pain, but if the inflammation and bulging of the damaged disc tissues irritate major spinal nerve roots, then lower extremity pain develops along with diminished sensation and motor coordination (i.e., a condition known as sciatica).

Most people suffering from both acute and chronic musculoskeletal injuries will recover from their symptoms within two weeks following the cessation of the offending stresses. Unfortunately for some, particularly if significant structural damage or neural trauma has occurred, the symptoms will persist, possibly for the rest of their lives. In the case of low back pain, approximately 70% of the population report that they have suffered at least one episode of low back pain during their working lives (18-65 years old), and about 20% of the population report that they are currently suffering from low back pain. It is well accepted that once a person has suffered an episode of low back pain, he or she is at elevated risk for a reoccurrence in the next year independent of other risk factors. In other words, the tissues have been injured and recovery may not be complete although the patient is temporarily free of pain.

Many studies have indicated that individuals with the more chronic and persistent injuries tend to have feelings of depression, anger, and loss of self-esteem. They may lose their hope that they will ever be able to work again, and may in a sense give up, becoming totally disabled by their musculoskeletal symptoms. Other individuals with the same apparent level of discomfort or severity of condition will continue to work despite their symptoms. When musculoskeletal complaints persist, health care providers, family, friends and employers often become frustrated and even skeptical about the physical nature and extent of the injury.

It is likely that an individual's reaction to an injury or disorder depends on many things such as his or her ability to adjust to the working environment and to the impairments. In all of these conditions, the longer a person is on sick or disability leave, the smaller the likelihood that the individual will return to work. Partially as a result of this observation, more attention has been placed on earlier comprehensive rehabilitation programs that address all of the potential barriers to returning to work, such as the need for physical reconditioning, psychological counseling, and redesign of the work environment. In addition, these programs attempt to reduce the need for surgery. Very few prospective studies have been undertaken which allow us to understand the complex interaction between the individual psychological reaction to an injury, the severity of the injury, and the nature of the work environment from both a social and physical perspective. One of the most controversial issues is the extent to which psychological causes explain impairment from the musculoskeletal injuries and disorders. Regardless of the precise interactions, in a very real sense, it is accepted that the afflicted individual can become both physiologically and psychologically disabled. This is one reason why musculoskeletal injuries are reported to cause so much loss in the "quality of life."

3.0 What are the Suspected Occupational Risk Factors?

3.1 Multi-Factored Risk Model

Several occupational risk factors have been linked to the incidence of musculoskeletal injuries. The most frequently cited occupational risk factors for disorders such as low back pain and upper extremity cumulative trauma disorders include: repetitive exertions, forceful exertions, awkward postures, mechanical stress, vibration, and cold temperatures. Often, workers are exposed to more than one risk factor. Currently, there are no extensively validated models to precisely determine a worker's risk level without some degree of uncertainty for a specific musculoskeletal disorder, based on his/her exposure to one or more of these occupational risk factors.

Repetitive exertions have been identified as one of the leading workplace risk factors for upper extremity cumulative trauma disorders. The repetitiveness of a lifting task also is associated with an increased incidence of low back pain. The repetitiveness of an operation can be described in several ways including: (1) the number of cycles per hour, (2) the number of lifts per hour, (3) the number of steps (exertions) included in each work cycle, or (4) the total number of exertions per hour.

Forceful exertions performed by the upper extremities in a hand-intensive task or by the whole body in a lifting situation are associated with the development of musculoskeletal injuries. The force requirements of a job are related to the weight of the object lifted or carried, the slipperiness of objects being gripped, and other manual reaction forces such as torque. Work pace, the use of gloves, and hand posture have been shown to increase the force requirements to perform a task.

Awkward postures of the upper extremities and torso have been identified by researchers and linked to the incidence of musculoskeletal disorders. Standing erect with the arms hanging at the side is considered to be a non-stressful posture. Working with the torso bent forward, backward, or twisted can place excessive stress on the low back. Other examples of high stress postures include reaching above mid-chest height, reaching behind the body, elevating the forearms, rotating the forearms, and bending the wrist forward, backward, or side to side.

Mechanical stresses are created when the soft tissues of the body are squeezed between a bone and an object in the work environment, such as when squeezing tools or leaning on a work table. Common sites of mechanical stress concentrations are the palm of the hand, forearm, fingers, elbow, back of the knees and buttocks/low back. Mechanical stress can be produced by pounding with the palm on a tool or work piece, using a tool that presses into the base of the palm, positioning the forearm or elbow on a hard surface, or sitting on an unpadded seat.

Vibration exposure is of primary concern when exposure is continuous or of a high intensity. Workers can be exposed to either whole body vibration or localized vibration. Whole body vibration is experienced by tractor, heavy construction, truck, and bus drivers. Localized vibration exposure of the upper extremities can be caused by the power or impact tools that are used in many materials assembly and maintenance operations.

Cold temperatures reduce manual dexterity and accentuate the symptoms of nerve impairment. Hands can be cooled below 20°C by exposure to environmental temperatures, contact with cold materials, or by exposure to cold exhaust air from a power tool.

More than one risk factor can often be identified for various tasks. In particular, the major cause of low back pain is lifting of loads which are either 1) too heavy, 2) placed in a location that requires an awkward torso posture, or 3) too frequently lifted or carried. Pushing, pulling and twisting of the torso also are considered hazardous to the low back in certain situations. It is estimated that perhaps as many as one out of three jobs in the U.S. require strenuous exertions which could be considered hazardous to a person's back.

Because it is not simply the weight of an object being lifted that causes over-stress of the low back, hazardous lifting conditions can only be recognized when several different job factors are considered. For example, lifting a 50 pound object held close to the body may impose less stress on the low back than lifting a 20 pound object at arms' length. If an object is lifted at the side of the body in a manner that requires the torso to be twisted or when the load is moved quickly, much higher back stresses can result than if lifted with both hands in front of the body or in a slow smooth motion. Similarly, repeated lifting of objects, such as on a production line, can cause muscle fatigue that produces low back pain. Stress on the low back can also be created by working in awkward postures when the body must support the weight of the torso alone without a load.

The upper extremity (and particularly the hand and forearm) also appears to be highly vulnerable to repeated forceful exertions. If manual tasks are performed in postures that concentrate the injurious stresses on specific shoulder, elbow, or wrist tissues, than those regions will deteriorate. Hence, working for prolonged periods with the arms raised above the shoulder causes upper back and shoulder pain, muscle fatigue, tendinitis, and bursitis. Similarly, turning the lower arm about its long axis, such as when screwing or unscrewing objects, while the elbow is in an extended position can produce elbow tendinitis. Repeatedly flexing and extending the wrist while forcefully squeezing a hand tool will result in tendinitis, tenosynovitis and even median nerve entrapment (i.e., carpal tunnel syndrome) at the wrist.

If a person is exposed to vibration, from either using a powered hand tool or riding in a vehicle without adequate suspension, the vibration energy is absorbed by the musculoskeletal system. When the vibration is of a certain magnitude and frequency it can combine with other stressors (e.g., postures, forces and repetitive exertions) to over-stress the musculoskeletal system. Likewise, cold temperatures may act in a synergistic fashion to increase musculoskeletal stress.

Psychosocial factors also are being linked to the incidence of musculoskeletal injuries. The most important psychosocial factors are related to time pressure, level of control, role of ambiguity, and job security. The effect of these factors on an individual depends not only on the level of the stressor, but also on a person's opinion concerning medical care, coping strategies, self-esteem, social support at home and at work, and family or financial problems. Though the evidence that psychosocial factors cause musculoskeletal injuries is circumstantial at this time, there is no doubt that they play a major role in determining the amount of suffering and disability incurred by an individual.

When a manual task is studied to identify the risk factors associated with the development of musculoskeletal disorders, it is necessary to look for the presence of multiple risk factors for each body joint. Examples of jobs which contain multiple risk factors will be discussed below.

Operations containing occupational risk factors

EXAMPLE 1. In a manufacturing facility, workers transfer a 54-pound cylinder head from a multi-level pallet to a 32-inch conveyor. 325 heads are transferred per hour. The operator loads cylinder heads for one hour and then has lighter duty tasks for 30 minutes. The heads are placed 16 per tier, and are stacked in five tiers on the pallet; the pallet is placed on a platform that is 23 inches above the floor, and the top height is 50 inches when there are five tiers of cylinder heads on it. The operator uses a special tool to pull distant heads closer to the front of the tier, but he/she still reaches as far as the middle of the tier to pick up the heads. Figure 1 depicts a worker lifting a cylinder head from the bottom tier. Among the most important risk factors associated with this operation include: (1) stressful torso and shoulder posture when picking up the head; (2) repetitive exertions, and (3) forceful exertions when picking up and transferring the head.

EXAMPLE 2. In another manufacturing facility, workers are seated at a conveyor and secure a metal plate to a small engine (see Figure 2). Workers use an air-powered pistol shaped tool to drive four screws and then fasten two connectors. 327 cycles are performed per hour. Among the most important risk factors associated with this operation include: (1) awkward wrist posture when driving the screws, (2) repetitive exertions, (3) forceful exertions to fasten the connectors, (4) vibration exposure while using the screwdriver, (5) mechanical stress concentrations on the hand from the sharp edges of the tool and the connectors, and possibly (6) exposure to cold temperatures if the connection between the tool and the air line is not secure.

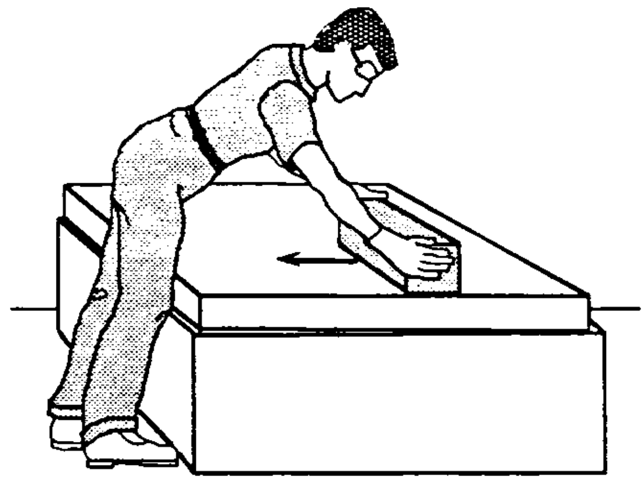


FIGURE 1
Transferring a 54-pound cylinder head from a multi-level pallet to a conveyor.

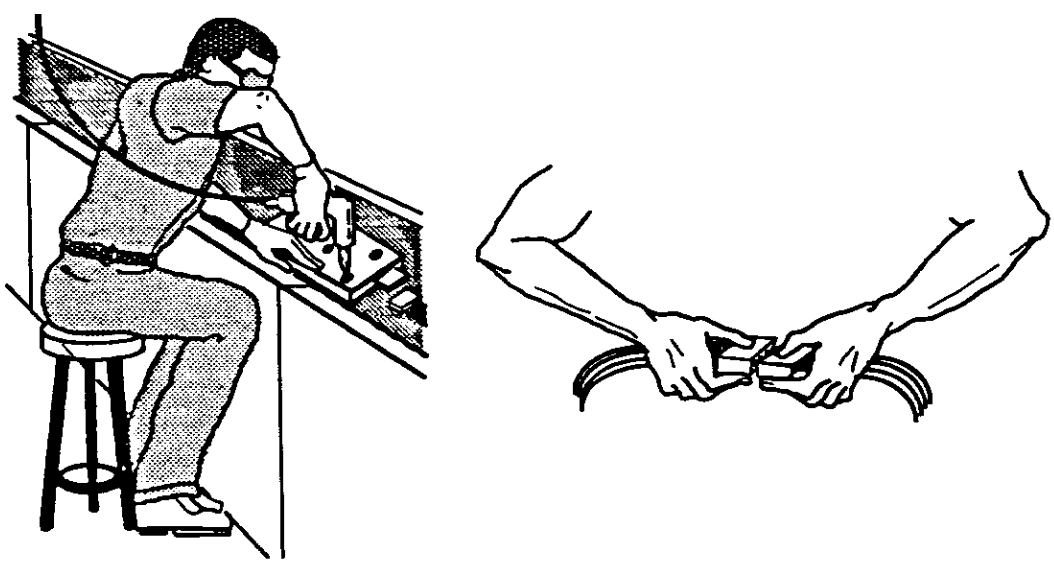


FIGURE 2
Workers secure a metal plate and fasten connectors.

EXAMPLE 3. The worker drives screws with a pistol shaped tool on a horizontal surface that is located at elbow height. In this posture, the worker has a deviated wrist, and an elevated elbow and upper arm (see Figure 3a). Other risk factors associated with this task are repetitiveness and forcefulness. The posture requirements of the job can be improved by using the pistol tool on a vertical surface (see Figure 3b).

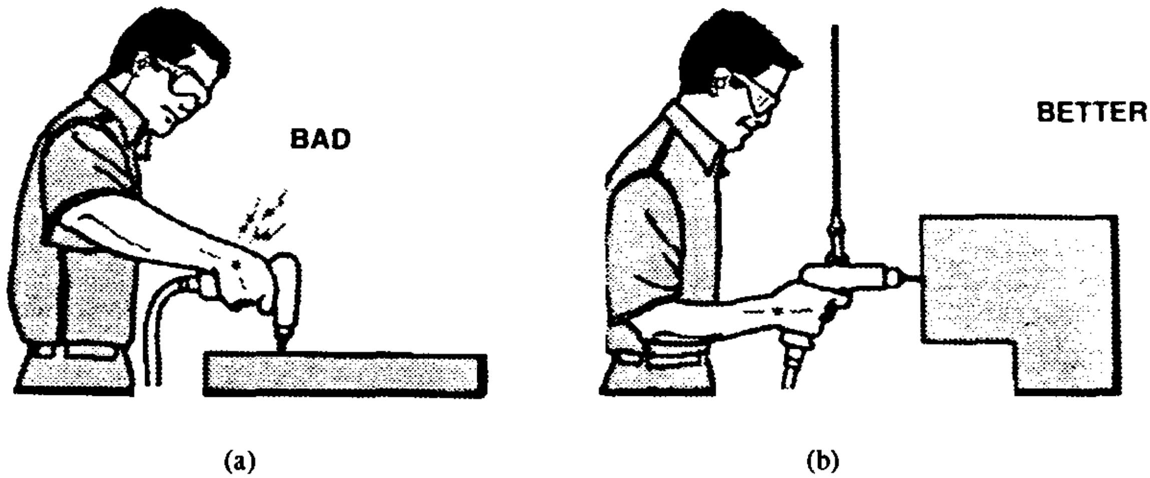


FIGURE 3
Worker drives screws with a pistol tool on a horizontal surface (a) and a vertical surface (b). (Adapted from Armstrong, 1986)

EXAMPLE 4. The word processor who types all day at this computer work station has her elbows resting on arm rests that are too far apart, elevated forearms, and wrists bent forward while resting on a hard tabletop (see Figure 4a). The risk factors associated with this operation include posture stress, repetitiveness, and mechanical stress locations on the forearm. Figure 4b illustrates some of the changes that can be made to this computer work station to reduce the impact of the risk factors. In this example a chair with adjustable and padded arm rests, seat pan height, and back rest height was introduced together with an adjustable table, an adjustable monitor, and a wrist rest.

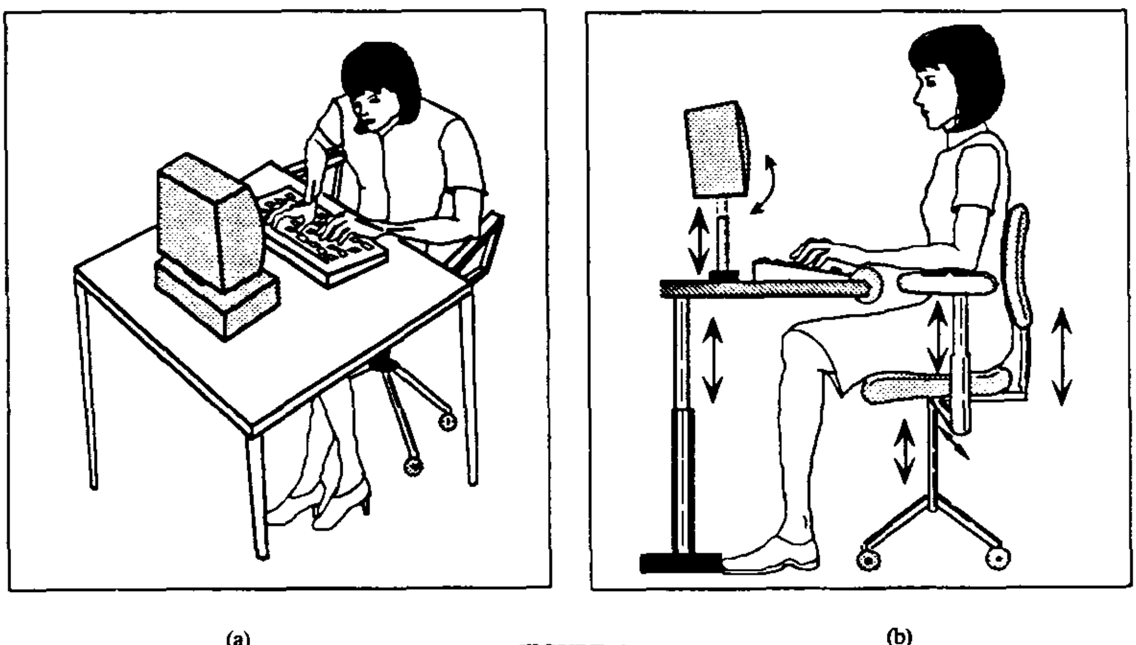


FIGURE 4
A keyboard operator uses a work station that contains several risk factors (a) and an improved work station with many adjustable features (b).

EXAMPLE 5. Cashiers scan 20 items per minute and the work pace is averaged over the entire work time (i.e., bagging and receipt of payment is included in total time). Consequently, the cashiers are actually scanning faster than 20 items per minute. The cashier in Figure 5a is using a horizontal scanner. Awkward wrist postures are present when scanning cans, milk, and other items. Grocery items often weight up to 20 pounds. The scale is often placed at the cashier's mid-chest height and this creates an elevated elbow and forearm when weighing fresh vegetables and fruits. A work station with an adjustable vertical scanner and a scale directly in front of the cashier that is installed in the work surface (see Figure 5b) can help reduce some of the stress associated with the job.

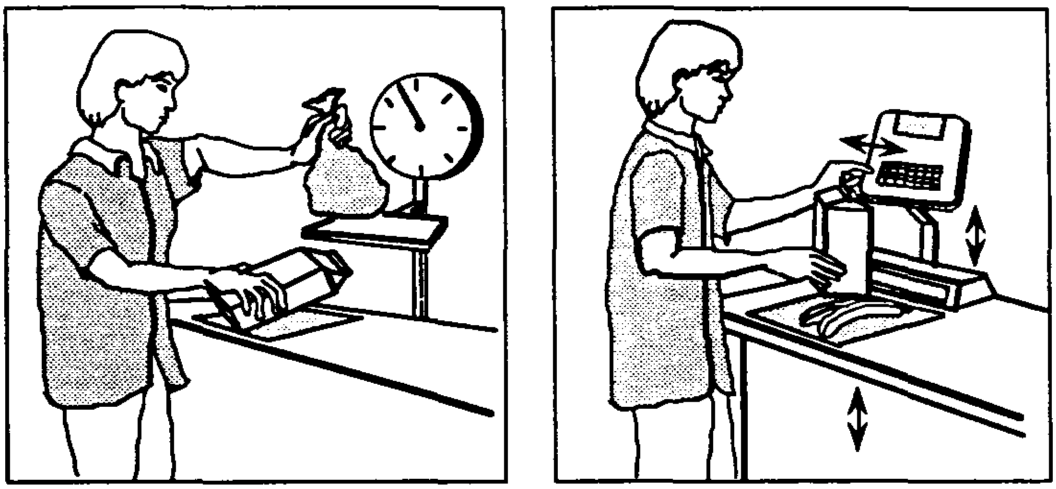
(a)  (b)

FIGURE 5

A grocery cashier scans items using a horizontal scanner (a) and an adjustable vertical scanner with the scale positioned on the work surface (b).

EXAMPLE 6. The assembly worker lifts a 15-pound glass window from a bin (see Figure 6a). The glass is positioned in slots to avoid sliding forward and consequently breaking. Because the worker must reach across the bin to pick up the glass windows, there is a large horizontal distance from the worker's ankles to his hands at the beginning of the lift. The lift originates at knuckle height and the window is placed into the car door at mid-chest height. One lift per minute is performed. By positioning the bin on an adjustable tilt table, the worker can keep the glass closer to his body and have an erect posture as he lifts the glass out of the bin (see Figure 6b).

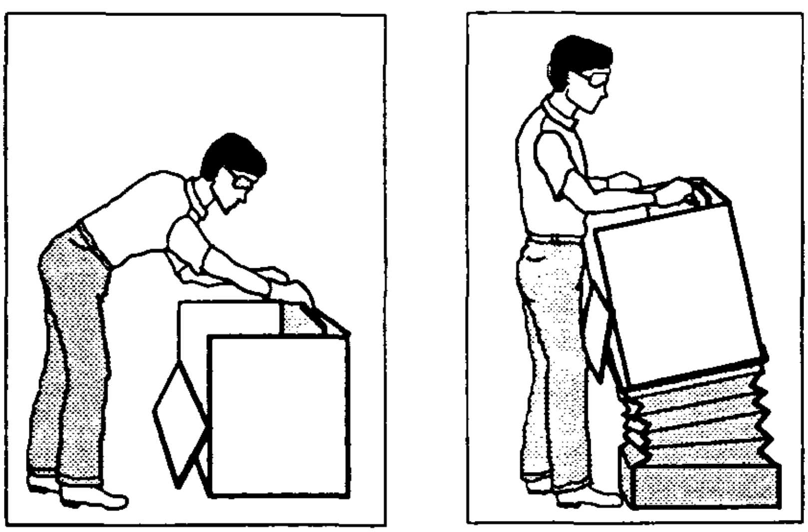
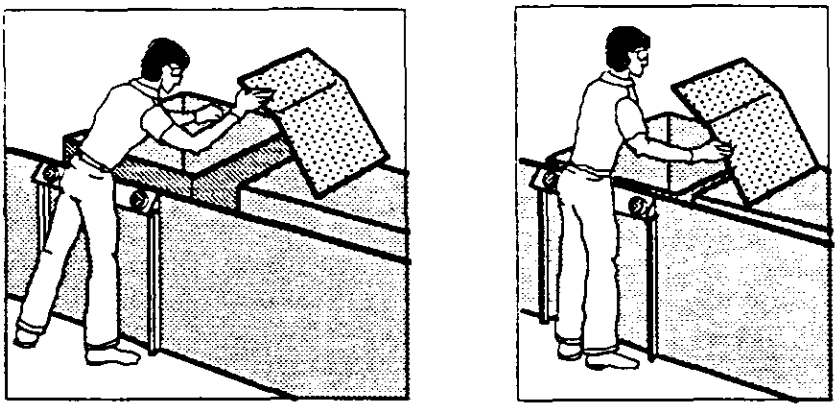
(a)  (b)

FIGURE 6

Worker lifts windows from a bin that is positioned on the floor (a) a bin that is located on an adjustable tilt table (b).

EXAMPLE 7. The assembly worker loads a 25-pound apron from a conveyor into a welding fixture. 450 loads per hour are performed (see Figure 7a). To load the apron, the operator must spend much of his day bent forward. By reducing the distance between where the operator must stand and the locating pins onto which the apron is positioned, the amount of forward bending is reduced (see Figure 7b).



(a) (b)

FIGURE 7

Worker loads an apron into a welding fixture that requires forward bending (a); and forward bending is reduced by locating the conveyor and bin closer to the worker (b).

In summary, it should be apparent that many different conditions can over-stress and injure the musculoskeletal system and that these are:

1. prevalent in the workplace,
2. complex and multifactorial in nature, and
3. require comprehensive programs to recognize and control.

The next section will discuss methods for identifying various job hazards.

3.2 Methods for Identifying Job Hazards

A systematic approach to job analysis is often used to document the whole task and work environment, and then identify the occupational risk factors. In the first stage, job documentation is accomplished through discussions with workers, supervisors and engineers, and by direct observation of a job. Job documentation should contain the work objective, work standard, the elements or steps required to be completed, the tools and equipment used, the physical characteristics of the work station, and the environmental conditions. The job documentation is then used to determine the existence of each occupational risk factor. In a detailed ergonomic assessment, each work element is examined to determine if any of the occupational risk factors are present. Once a risk factor is identified, the work characteristics that effect the potential severity of the risk factor are documented. Checklists have been developed to help lead the analyst through the job documentation and ergonomic assessment process.

Several computer and analytical models have been developed to estimate the physical requirements of work. Both a *two-dimensional* and *a three-dimensional static strength prediction model* have been developed to estimate low back spinal compression forces and to predict static strength requirements of manual material handling tasks such as lifts, pushes or pulls. Dynamic biomechanical models have been developed and validated in laboratory settings. These indicate that peak stressors created during certain types of manual exertions could cause increased risk of injury. A *metabolic energy expenditure prediction model* estimates the energy requirements of a wide variety of manual material handling jobs. The model predicts the energy expenditure associated with each element and the entire job. *Posture analysis* can be performed to identify the awkward postures present in each job cycle and the percentage of the cycle that the worker spends in all the identified postures. The *NIOSH Work Practices Guide for Manual Lifting* determines the allowable weight of a load that can be lifted for a specific condition.

Computer aided design in conjunction with anthropometric manikins can be used to view the interaction of the worker with the work station before a new job is actually constructed or current job is redesigned. These mock-ups can be used for early identification of potential occupational hazards.

Researchers are beginning to combine various prediction models into integrated software packages.

One system combines three-dimensional static strength and back compression models, a metabolic energy expenditure prediction model, the NIOSH *Work Practices Guide for Manual Lifting*, a low-level motion time prediction model, a posture prediction algorithm, and a three-dimensional computer graphics manikin. A database of tasks for a particular operation is created, and then the appropriate models can be used to estimate the physical stress of specific tasks, or the physical stress for the entire operation.

New instrumentation is now available to estimate the stress of an occupational task while the worker is performing it. *Electromyography* (EMG), recording the electrical impulses of the muscles, can be used to estimate the force requirements of a job. *Goniometers* and other *motion analysis systems* can be used to measure postures as people are working.

Discomfort questionnaires have been successfully used to identify work station parameters that need to be changed. A discomfort questionnaire usually consists of a body diagram in which workers shade the areas of the body at which they feel discomfort while working. Then workers rate the severity of the discomfort at each identified body part. Based on the discomfort ratings and observation of the job, the tasks that lead to the discomfort can be identified and modified. After the modifications to the work station are complete, the discomfort questionnaires can be used again to measure the change in worker discomfort.

Questionnaires have also been developed to measure *psychosocial stress* experienced at work. These surveys attempt to quantify a worker's mood; perception of control; relations with supervisor, management and co-workers; and other variables associated with the psychosocial stress at work.

4.0 Non-Occupational Factors and the Risk of an Occupational Musculoskeletal Injury

The epidemiological studies of musculoskeletal disorders or injuries of the type that are commonly associated with work factors are still at an early stage and have tended to focus more on low back pain than on disorders of the upper extremity. Results of surveys done on active workers in high-risk industries may differ from those done on the general population. The former tend to identify most clearly the role of the work-related factors while the latter tend to identify the non-occupational factors. In both workplace and community studies, preexisting medical conditions rarely explain the majority of new cases of musculoskeletal disorders or injuries such as low back pain or shoulder pain. Examples of these preexisting conditions are rheumatoid arthritis, diabetes mellitus, and myxedema (very low thyroid function), all of which have been associated, for example, with carpal tunnel syndrome.

Musculoskeletal injuries or disorders such as low back pain and carpal tunnel syndrome can be caused by non-occupational factors or exposures. While epidemiological studies of low back pain the general population have, in general, failed to identify factors which are strong predictors or correlates of low back pain, there is some evidence that cigarette smoking, number of births or pregnancies, distance traveled to work, and perhaps heavy alcohol consumption are modestly related to the risk of developing low back pain. Psychological factors often affect the reporting of and recovery from back pain although it is difficult to determine whether the psychological factors predate the onset of back pain or are the result of it. Some occupational factors such as lifting, twisting, prolonged sitting, and driving, of course, occur during recreational activities and may be a cause of low back pain. Medical evaluation of low back pain conducted by primary care physicians often fails to identify the specific cause of the low back pain.

The work-related disorders of the upper extremity are a diverse group of conditions ranging from carpal tunnel syndrome and rotor cuff tendinitis to regional pain which cannot be related to a specific anatomical structure. The diversity of these conditions, most of which have not been studied epidemiologically, makes it difficult to generalize about nonoccupational causes of these conditions. Non-occupational activities, such as sports activities, certainly can cause a variety of tendinitis of the upper extremity. The best studied non-occupational causes of carpal tunnel syndrome are co-existing medical conditions such as rheumatoid arthritis, acute trauma, and pregnancy.

The community and workplace studies have also addressed whether the rate of musculoskeletal complaints, disorders or injuries vary by gender and age. In community-based studies, the prevalence of low back pain is not strongly related to age after the age of 30, or to gender. In 1988, the National Center for Health Statistics conducted the National Health Interview Survey in an effort supported by NIOSH. It inquired about back and hand pain in national representative samples of 60,000 Americans to assess the relative magnitude of work-related pain. In this survey the prevalence of back pain was similar in men and women (18% and 17%) and varied little with age. Men had a somewhat lower prevalence of hand discomfort than did women (8% versus 11%). The prevalence of hand discomfort increased with age from a rate of 6% for those less than 35, to 14% for those over 55. In workplace studies conducted by NIOSH, age is generally not a strong predictor of hand discomfort or work-related disorders.

One of the upper extremity disorders that has been studied both in the community and in the work force is carpal tunnel syndrome. While most clinical series of carpal tunnel surgery report a ratio of about one to three (men to women), studies from the workplace do not consistently report a higher risk for women. In a study of occupational carpal tunnel syndrome based on the workers' compensation system in Washington State, the mean age and female/male gender ratio differed substantially from the population-based studies (work-related—37 years and F:M=1.2:1; and population-based all cases—51 years and F:M= 3:1).

From biomechanical studies it is logical to hypothesize that some personal characteristics of an individual such as the strength of the muscles of the trunk or the size of the carpal tunnel might be associated with the risk of developing a musculoskeletal disorder or injury. General studies, however, have not consistently demonstrated that there are any reliable or strong personal predictors of upper extremity disorders or injuries. Although it is reasonable to assume that individuals with work-related disorders who return to the same jobs that caused or triggered their initial injury have an increased risk of developing a second disorder, this has not been studied for upper extremity disorders. There is evidence that a history of recent low back pain is associated with a modest increase in the future risk of additional episodes of low back pain. With regard to low back pain, there is some evidence that stronger individuals may be at a lower risk of developing low back pain when performing lifting tasks over the period of a year. However, there is also some evidence which also suggests that muscle strength and tissue resistance to future stresses may not be strongly related. In a ten-year prospective study of both white and blue collar workers, there was no relationship between the strength of trunk flexors or extensors and the ten-year incidence of low back disorders. However, this and similar studies are limited because the specific job demands were not related directly to the workers' individual characteristics, as was done in earlier, short-term studies that found a positive relationship between job related strengths and injury rates.

5.0 What Fundamental Research is Needed to Understand the Causes of Occupational Musculoskeletal Injuries?

What follows in this and the next section are summaries of recommendations for specific research needed to understand and prevent occupational musculoskeletal injuries. These recommendations represent the consensus of the attendees from the two different Workshops. They are presented within the framework developed by the NIOSH Board of Scientific Counselors. One workshop dealt with research issues, and their results are summarized in Section 5.0. The second workshop discussed prevention strategies, and their recommendations are contained in Section 6.0. The topics in the two sections are as follows:

Section 5.1	Identification of Potentially Hazardous Job Stressors
Section 5.2	Measurement of Worker Exposures
Section 5.3	Identification of Individuals and Populations at Special Risk
Section 5.4	Mechanics of Occupational Musculoskeletal Injury
Section 6.1	Effective Hazard Surveillance and Related Injury Identification
Section 6.2	Development of Effective Injury Control and Prevention Strategies
Section 6.3	Effective Use of Controls

5.1 Identification of Potentially Hazardous Job Stressors

It should be clear from the preceding information that the human musculoskeletal system is vulnerable to a variety of stressors common to many different occupations. One goal of prevention programs is to be better able to identify those activities that act singularly or in combination to produce a significant stress on the musculoskeletal system.

The Workshop participants recognized that overt and strenuous physical acts, such as those associated with lifting, carrying, and handling of heavy loads, can be reasonably well identified by contemporary job analysis procedures, though these procedures may not be widely used (see subsection 6.0). It is much more difficult to recognize tasks that may stress specific musculoskeletal components due to repeated but less forceful exertions performed sometimes in awkward postures. The Workshop participants believed that it is very important to have improved methods by which a large variety of manual tasks can be objectively studied in a variety of manufacturing and service industries. The participants proposed that new or improved job stress analysis methods are needed which will identify musculoskeletal stressors associated with:

1. work performed in pace with a machine, or when extra pay is provided to encourage a worker to exceed normal production rates (e.g., piece pay incentives);
2. physical movements performed at high speeds and with high precision;
3. static exertions performed for long periods (e.g., while maintaining an awkward posture or while working at a video display terminal); and
4. localized mechanical stresses that compress musculoskeletal tissue and compromise circulation (e.g., when sitting on a hard chair

without adequate seat pan padding or with poorly designed back and arm supports).

The Workshop participants also expressed concern that some job requirements may act in synergy with other factors to over-stress the musculoskeletal system. The following were cited as examples wherein certain stressors may not be identified as unusual by themselves, but when associated with other manual exertions, the combination may be hazardous, and should be identified for further evaluation:

1. low level exertions that are repeated quite frequently (e.g., VDT keyboard entry tasks);
2. an adverse psychosocial climate at work as characterized, for example, by ambiguous work roles, insufficient supervisory support, lack or work autonomy, job insecurity, etc.;
3. extended work days and/or changes in one's work shift;
4. vibration that is either localized (e.g., from hand tools) or affecting the whole-body (e.g., from vehicles);
5. heat and/or cold work environments.

Chemical exposures at work and other exposures such as cigarette smoking might be important determinants of musculoskeletal disorders. Studies are needed to determine whether these non-physical exposures substantially increase the risk of exposures to other occupational factors.

5.2 Measurement of Worker Exposures

The preceding section has listed a variety of specific work conditions wherein research is needed to develop and validate methods that can be used to correctly identify harmful stresses on the musculoskeletal system. To enable such stressors to be quantified, the Workshop participants urged that research be performed to improve the technology needed to accurately and reliably *measure* (quantify) the following job and work performance attributes which singularly, and in combination, may produce damage:

1. repetitive motions of small body segments (e.g., finger and hand motions used in fast keying operations);
2. extreme work postures (e.g., reaching, twisting, bending);
3. internal muscle exertion levels associated with different types of manual work that are estimated using electromyographic, acoustical myographic, and other yet to be identified methods;
4. external force, torque and pressure requirements of a variety of manual jobs (e.g., as caused by grasping, lifting, pushing and pulling of objects);
5. vibration levels and frequencies on jobs caused by hand tools, vehicles and other moving equipment;
6. varied work/rest periods throughout the work shift, and prolonged work hours as well as rotating shift work.

It also was recommended that the above job and work attributes be measured by statistical sampling methods where possible. Developing and using such sampling plans will reduce future need to perform continuous monitoring of workers. Statistical sampling methods can also provide an efficient means to include larger numbers of workers and jobs in future job stress surveys.

As the preceding recommendations indicate, there was agreement that we need to improve the methods used to identify and measure job stressors that may be hazardous to the musculoskeletal system. In this context, the role of biomarkers and histological data to confirm the presence of specific tissue damage was discussed. Though laboratory research to refine such tests and procedures for improved diagnostic purposes was supported in general by the Workshop participants, at this time, this type of effort was not deemed to be as important to prevention of musculoskeletal injuries as the other actions recommended in this section.

5.3 Identification of Individuals and Populations at Special Risk

The capacity of individuals to perform most physically stressful tasks without harm varies substantially in any normal population. As a result, the probability that a given task may over-stress a particular individual depends on the specific characteristics of the individual. In this context, the Workshop participants proposed that both laboratory and field based research is needed to improve the various methods and procedures needed to assess individuals who may be at elevated risk due to prior injuries or restricted work capacities. In this regard, it was proposed that the research should concentrate on improving those worker evaluation methods that are *directly related* to specific job requirements, as opposed to generic physical performance tests of strength, flexibility and endurance. Generic physical performance tests were recognized to be of benefit in determining the general physical fitness of an individual relative to peer population norms, but such information has not been shown to be important in assessing an individual's risk level when assigned to a specific job or manual task. It was concluded that individual risk assessment is a much more complex matter that will necessitate comprehensive research programs based on knowledge of both job and worker attributes. One of the principal reasons that valid individual risk assessments are difficult to establish scientifically is the need to measure on a long-term basis the changes in an individual's capacities, job demands, exposure to non-occupational factors and health outcomes. Though expensive and time consuming to conduct, the need to develop and validate job-related physical ability tests that will accurately predict the risk of future musculoskeletal injuries is supported. Information from such tests will also provide a basis for better design of the work environment to accommodate older workers and those with acknowledged impairments. The recently passed American with Disabilities Act will encourage wider spread use of job-related testing and evaluation technologies. A more accurate ability to predict future risks should not be used as justification for failure to adopt preventive strategies that rely on primary prevention, however.

5.4 Mechanics of Occupational Musculoskeletal Injury

Though it is possible to develop effective prevention strategies based on epidemiological studies that result in a positive statistical association between certain job and/or worker characteristics and increased incidents of musculoskeletal injury, it is always desirable to understand how a particular job stress actually injures specific musculoskeletal tissues. Since the insult to musculoskeletal tissue is normally of a mechanical nature (i.e., the force or stress on a tendon, muscle, ligament, or cartilage exceeds the tissues' tolerance), the Workshop participants strongly urged that *fundamental biomechanics research* be supported to understand how specific occupational stressors cause tissue trauma and disability. In this context, the following types of basic research were recommended for increased support:

1. Worker population physical stress tolerances (strain limits) for different musculoskeletal tissues must be more precisely determined through both biomechanical and psychophysical (discomfort rating) studies.
2. Biomechanical models now being developed to simulate and predict the physical stressors associated with manual jobs need to be improved to more accurately predict internal tissue stresses on specific muscles, tendons, nerves, and joint structures. These models need to include normative tissue failure limits (from research in 5.4.1 above), thus being able to predict the risk of certain types of musculoskeletal injuries when individuals perform specific manual tasks.
3. Anatomical regions in need of further fundamental occupational biomechanics research are (in descending order of importance):
   - Back and Shoulder/Neck Complex
   - Upper Extremity (including elbow and wrist)
   - Lower Extremity (including hip, knee and ankle).

   The importance of job related biomechanics research on the lower extremity is expected to increase as more older workers comprise certain job categories that require prolonged standing and walking.
4. Empirical laboratory and field studies are needed to verify biomechanical model predictions of musculoskeletal stress. Though animal studies may be of some value, the Workshop participants supported the development and use of newer sophisticated physiological measurement techniques (e.g., EMG, Acoustic Myography, tissue pressure) with human volunteers for such studies. Also needed are epidemiological studies that include the evaluation of newer biomechanical model stress predictions and physiological measurements.

6.0 What Research is Needed to Provide the Most Effective Prevention Strategies?

The recommendations is the preceding Section 5 are meant to guide research toward better understanding of the causes of occupational musculoskeletal injuries. This section presents recommendations that emphasize the need to develop, implement and evaluate a variety of prevention strategies.

6.1 Effective Hazard Surveillance and Related Injury Identification

Currently, most surveillance systems fail to collect information simultaneously on job hazards (the level of exposure to stressors) and health outcomes. Research into the design and evaluation of surveillance systems that effectively collect, analyze, and utilize this combined information to target intervention activities is needed.

Hazard Surveillance

One of the challenges is to develop and validate effective tools for assessing the presence of job risk factors. Since hazard surveillance may not require a high level of quantification or precision in assessing exposure, simple tools like checklists may be effective. Checklists may be a valuable tool because they can be used by people with limited ergonomics training but with great knowledge of the job, and require a small amount of time to evaluate a job task. One of the exposure parameters which will require the most careful validation is the estimation of force. This will require considerable methodological development and evaluation.

In addition, simple surveillance tools are desirable to assess segmental and whole body vibration, localized mechanical stresses, and postural variability in workers performing the same tasks. Surveillance tools are needed to tackle two other areas of job exposures that are likely to be of increased importance in the future; these are psychosocial factors which currently are measured strictly by the use of questionnaires, and the effect of micro pauses and rest work cycles. If simple methods can be developed for jobs without complex and highly variable tasks, then the challenge will be to extend the methods to the more difficult situation of complex and variable job tasks.

In addition to checklists, a continuing area of interest is the clarification of the roles of the worker and supervisor questionnaires. While not useful in quantifying risk factors, questionnaires may be useful in determining whether risk factors are present or absent. Questionnaires may be most applicable to jobs that involve a large number of varied and complex tasks. Psychophysical scaling of perceived risk factors may be more useful than checklists when the jobs are complex and varied. Workshop participants gave top priority to studying the integration of subjective perception of risk with direct objective methods of assessing risk factors or exposure conditions. Workshop participants recognized that some methods for job analyses such as checklists, questionnaires, the Ovaco Working Posture System (OWAS), and others, have already been developed for both research and surveillance purposes. The limitations and strengths of each possible approach for effective hazard surveillance need to be evaluated. These studies need to focus not only on how accurately these systems identify job risk factors, but also whether these methods are feasible surveillance tools. For an approach to be feasible, it should require only a modest amount of user training and not be too time consuming to use. It will be important to determine user acceptability for new proposed surveillance tools. The proper tools will not only need to consider the type of exposures, but also the size of the exposed population.

Health Surveillance

While job hazard surveillance is an important area, the Workshop had some recommendations regarding health surveillance or the identification of injuries and disorders. Health surveillance activities at the national, state, corporate, and plant level are based on the use of existing records. Examples of this passive surveillance are workers' compensation records or the OSHA log. Current consensus contends that passive surveillance data can be useful to trigger follow-up investigations. Evaluation of such passive data systems is needed to examine whether or not this is valid. One of the features of existing systems that need further standardization is the recording and detection of adverse health outcomes. One approach is the development of improved case definitions, however, this will be difficult until there is the development of more precise and accurate clinical diagnostic techniques for many musculoskeletal regional syndromes such as low back, neck or hand-forearm pain. Workshop participants proposed that surveillance data may be useful in research to determine whether the success of rehabilitation of workers with injuries is related to the duration and intensity of their past exposure to stressful work. In addition, research is needed to determine if surveillance techniques, which include a history of a workers' past injuries from previous jobs and specific information about a person's functional limitations, might provide better information about predisposition to future injury.

6.2 Development of Effective Injury Control and Prevention Strategies

Workshop participants identified four areas for injury control and prevention: 1) engineering controls, 2) personal protective equipment, 3) administrative controls, and 4) adequate treatment that includes rehabilitation of the injured worker. Although a division between engineering and administrative controls was cited, many felt that this separation may be detrimental to an effective prevention program.

Engineering Controls

Engineering-based specifications and designs determine a job layout and process, which in turn creates the hazardous exposures of a specific job. Engineering controls are designed to reduce or entirely eliminate the hazardous exposures. However, following the installation of controls, it is rare to re-evaluate the new exposure conditions to examine if the risks have been substantially reduced. The Workshop recommended that studies should be undertaken to investigate the effectiveness of existing and proposed engineering controls. Some of the evaluation approaches are not complex. For example, the use of the workers' assessment of discomfort and mild symptoms before and after engineering changes can be very useful.

Additionally, these studies should also examine the approaches used to determine if engineering controls are required, and to suggest specific engineering solutions. For example, we have had tools for over ten years to predict the risk of lower back pain and injury (e.g., NIOSH *Work Practices Guide to Manual Lifting*), but these tools have not been extensively validated in industry. Basic biomechanics research is still needed in the area of developing new engineering controls for low back injury and Upper Extremity CTD (see Section 5.0). In addition, field studies are needed to compare the variety of methods of controls now being proposed and developed.

Mechanical aids to lift and transport objects (e.g., hoists, articulated arms) are also used in industry. Research is needed to determine their effectiveness in preventing injury, and to identify possible additional stressors they may cause if improperly designed or used.

Personal Protective Equipment

Although Workshop participants strongly preferred the use of engineering controls to eliminate jobs hazards, personal protective equipment (PPE) such as gloves, padding, wrist splints, wrist rests, and weight lifting belts, are commonly used by workers in an attempt to reduce injury. Many Workshop participants strongly felt that workers and companies are using PPE in place of good workplace design and other engineering controls. Some participants felt that resources should be immediately directed to determining the efficacy of PPE-based approaches, since claims of injury prevention are often made, but rarely substantiated by scientific studies.

Administrative Controls

Workshop participants strongly cited a need to determine if job rotation, schedules, and varied work/rest cycles reduce worker stressors. For highly repetitive jobs (e.g., keyboard entry work), further research is needed to determine how to best control the stresses on specific musculoskeletal tissues.

Workshop participants recognized a great need for objective and quantitative standards or guidelines for evaluation of hazardous workplaces. Substantial research may be needed to justify the scientific basis of quantitative risk assessments of the relationship between exposure and injury or disorder. Priority should be given to common work situations or processes such as video display terminal work. One important issue in further research is selecting the best measures of exposure, so that exposures in a diverse industry can be studied to delineate better effect-response relationships.

Adequate Treatment and Rehabilitation

The principal focus of preventive activities should be directed at primary prevention, which relies on reducing or stopping exposure. Nevertheless, many work-related musculoskeletal injuries and disorders will continue to occur for some time, and many similar disorders will be common in the workforce because they have non-work etiologies. To reduce the human suffering and economic burden on individuals and society, research is required on the development and evaluation of effective treatment and rehabilitation programs. The rehabilitation process must include a comprehensive approach. Adequate attention to all aspects of the problem is needed. This includes reconditioning of the injured worker, which may comprise of a work hardening program, evaluation and counseling regarding the psychological and emotional consequences of pain and disability, and an assessment of the total work environment where the worker will return after his or her care is completed. It is also recommended that a case follow-up mechanism be in place.

6.3 Effective Use of Controls

The successful implementation of a control program undoubtedly requires more than the identification of high-risk jobs by use of hazard or health surveillance data and the understanding of the engineering principles required to redesign the hazardous jobs. It requires management commitment, training of employees and supervisors, employee involvement, and incorporation of ergonomic considerations into the design of new work processes. Determining the best methods to ensure the inclusion of each of these key elements into a control strategy will entail additional research to evaluate each of these elements. These evaluations of the effectiveness of control programs should study a wide range of outcome variables including: health outcomes, symptoms, and the rate of recurrences; employee acceptance or satisfaction of job redesigns; effects on productivity; and managements' evaluation of the impact of the control program. Research into understanding more effective ways to disseminate control information and train employees and supervisors is also highly desirable.

To disseminate information about ergonomic controls, studies are necessary to determine the utility of management and worker training and other means of communication. Two exemplary ways to study the effectiveness of information dissemination would be to: 1) investigate organizational parameters, and 2) test workers and supervisors about ergonomic control information. Both basic research and field work are needed to assess the evaluation of control information dissemination.

7.0 Summary and Recommendations

There is little doubt, based on the data and experiences summarized by the participants in both the

Conference and Workshops, that Occupational Musculoskeletal Injuries (OMIs) encompass the most costly types of injuries (est. $100 billion annually) and affect several million workers each year. Low back pain episodes continue to represent the more severe and disabling form of such injuries across all industries. More recently, upper extremity cumulative trauma disorders (UECTDs) have been found to be prevalent and a large cause of work disability in a diverse number of occupations and industries. Both low back pain and upper extremity disorders are characterized by a wide range of severity from minor and infrequent episodes to permanent disability. The economic and human cost to society, employers and employees is very substantial.

It has become very clear to all involved in prevention of all forms of OMIs that a great deal of new knowledge is needed, both to understand the cause of specific types of OMIs, and to develop and validate effective, work-centered prevention and rehabilitation strategies. In this context, the following general recommendations are delineated, based on the specific results of the process summarized in Sections 5.0 and 6.0 of this document:

1. An improved capability to **identify hazardous job stressors** is needed that recognizes how sometimes subtle physical exertions on jobs combine with other risk factors (such as awkward postures, high repetition, long work cycles, cold temperatures, vibrations, or high amounts of psychosocial stress) to create musculoskeletal tissue trauma, pain and disability.

2. An improved ability to **objectively measure and quantify job stresses** believed to cause OMIs is needed. In particular, we must develop more sensitive measurement systems, capable of accurately describing small body motions, and static and dynamic forces now required in many jobs that are known to cause localized tissue trauma and disability.

3. Most participants believed that there is a rapidly growing need to develop objective medical tests to **identify people who may be at special risk** of OMIs when exposed to certain job conditions. Such tests need to be carefully constructed to be safe, reliable, accurate and efficient (low operational time cost); to be directly related to the job requirements; and to be highly predictive of an individual's risk level when required to perform a specific manual task in a job. Other participants were concerned about the feasibility for this type of testing in a prevention program from a policy or scientific perspective.

4. Much **more fundamental biomechanical and other types of research** are needed to understand why for the majority of the OMIs the specific nature of the damage to the body cannot be conclusively established during routine clinical evaluations. Worker population biomechanical tolerance data are needed to specific tissue and musculoskeletal structures. In addition, biomechanical models that more accurately predict tissue stress levels during work are needed, as well as empirical studies to validate the output from these models.

5. **Job hazard surveillance and OMI reporting systems** need to be improved. These should be easily implemented (user friendly) systems that link job hazard data (from job evaluations, checklists, psychophysical effort reports, and worker questionnaires) to medical injury and illness reports in a timely fashion.

6. A variety of OMI control procedures and equipment are available today. These **controls need to be carefully evaluated** to determine their effectiveness in preventing future OMIs, and the operational conditions under which they are effective. Additional research is recommended to refine the effectiveness of early comprehensive medical interventions and rehabilitation strategies.

7. The design of various **industrial planning and social/organizational issues** need to be studied to understand how these impact the implementation of various control strategies. For example: What level of ergonomics training is needed? Who should be involved in implementing ergonomic changes? Will progressive reduction in ergonomic hazards be associated with improvements in productivity and quality?

Occupational musculoskeletal injuries are now being recognized for the harm they cause to both workers and organizations. Unfortunately, both the science and technology needed to prevent these injuries is not completely developed or disseminated. This has resulted in a myriad of different types of preventive strategies being proposed by many different organizations, with varying degrees of scientific basis. The need to critically evaluate these approaches as well as provide a more basic understanding of the prevention of OMIs must now be vigorously pursued.

8.0 CONFERENCE OUTLINE AND WORKSHOP PARTICIPANTS

8.1 Conference Outline

Monday, April 8

7:30 AM - Registration, Rackham Building

8:30 AM ***Session: Occupational Musculoskeletal Injuries—National and International Perspective***

Welcome

Session Chair: *Don B. Chaffin, Ph.D.*, Professor & Director, Center for Ergonomics, The University of Michigan

Welcome & Congressional Interest in Injury Prevention
Cynthia Hudgins for Hon. Carl Pursell, U.S. House of Representatives

Strategic Role of NIOSH
J. Donald Millar, M.D., Assistant Surgeon General; Director, NIOSH

Strategic Role of OSHA
Gerard Scannell, Director, OSHA

The Swedish Strategy
Carl Asklöf, Director, Swedish Work Environment Fund, SWEDEN

11:00 Panel Discussion,
Panel Chair: *J. Donald Millar*, Chair

11:45 Luncheon, Michigan League Ballroom

1:00 PM ***Session: Defining the Scope of the Problem and Some Current National Intervention Strategies***
Session Chair: *Tom Bender, M.D.*, Director, Division of Safety & Research, NIOSH

Epidemiology and Cost of Occupational Low Back Pain
Stephen L. Gordon, Ph.D., Musculoskeletal Diseases Program Director, National Institute of Arthritis and Musculoskeletal and Skin Diseases

Epidemiology and Cost of Upper Extremity Cumulative Trauma Disorders
Lawrence J. Fine, M.D., Dr.P.H., Director, Division of Surveillance, Hazard Evaluations and Field Studies, NIOSH

Using the 1981 NIOSH "Work Practices Guide for Manual Lifting" As the Basis for Engineering Materials Handling Jobs
Gary Herrin, Ph.D., Professor, Industrial & Operations Engineering, The University of Michigan

Revisions in NIOSH Guide for Manual Lifting
Vern Putz-Anderson, Ph.D., Section Chief, Psychophysiology & Biomechanics, Division of Biomedical and Behavioral Science, NIOSH

2:20 PM Break

2:40 PM ***Session: Prevention Methods—Do We Know If They Work?***
Session Chair: *Janet Haartz, Ph.D.*, Director, Division of Biomechanical & Behavioral Science, NIOSH

Redesign of Materials Handling Jobs
M.M. Ayoub, Ph.D., Professor Industrial and Biomechanical Engineering, Texas Tech University

Redesign of Jobs for Controlling Upper Extremity Cumulative Trauma Disorders
Thomas J. Armstrong, Ph.D., Professor, School of Public Health, The University of Michigan

Occupational Stress in Musculoskeletal Disorders
Steven Sauter, Ph.D., Section Chief, Motivation and Stress Research, Division of Biomedical and Behavioral Science, NIOSH

3:40 PM **Panel Discussion**
Panel Chair: ***Steven Gordon, Ph.D.***

5:00 PM **Adjournment**

Tuesday, April 9

8:00 AM
Session Chair: *John Treibwasser, M.D.*, Corporate Medical Director, Ford Motor Company

Evaluation of High Risk Workers
Gunnar Andersson, M.D., Ph.D., Professor, Orthopaedic Surgery, Rush Institute, Chicago, IL

Multidisciplinary Rehabilitation of Work-related Upper Extremity Disorders
Michael Feuerstein, Ph.D., Center for Occupational Rehabilitation, University of Rochester Medical Center

Worker Training & Rehabilitation Methods
Margareta Nordin, RPT, Ph.D., Program Director, Ergonomics & Occupational Biomechanics, New York University, and Director, Occupational and Industrial Orthopaedic Center, Hospital of Joint Diseases

Worker Involvement Programs
Barbara Silverstein, Ph.D., Manager, Safety and Health Assessment Research Program, State of Washington

9:40 AM ***Session: Organizational Intervention Strategies***
Session Chair: *Frank Mirer, Ph.D.*, UAW

Development of and Experience with OSHA "Ergonomics Program Management Guidelines for Meat Packing Plants"
Ray Donnelly, Director, Office of General Industry Compliance Assistance, US/DOL, OSHA

Insurance Company Programs
Stover Snook, Ph.D., Liberty Mutual Insurance Company

Occupational Medical Programs
Bruce Dickerson, M.D., Past President, ACOM and Retired Medical Director, IBM

Organized Labor Programs
David LeGrande, Communication Workers of America

Panel Discussion
Panel Chair: ***Lawrence J. Fine, M.D., Dr.P.H.***

Conference Summary
Don B. Chaffin, Ph.D.

12:00 PM Adjournment of Conference

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Susan Palmiter, Ph.D.-Recorder

R = Research Strategies Workshop
Don Chaffin, Ph.D.-Chair
Christine Black, B.A.-Moderator
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