Work Organization, Job Stress, and Work-Related Musculoskeletal Disorders

Pascale Carayon, **Michael J. Smith,** and **Marla C. Haims**, University of Wisconsin-Madison, Madison, Wisconsin

Recent studies indicate potential links among work organization, job stress, and work-related musculoskeletal disorders (WRMDs). In this paper we propose several pathways for a theoretical relationship between job stress and WRMDs. These pathways highlight the physiological, psychological, and behavioral reactions to stress that can affect WRMDs directly and indirectly. One model stipulates that psychosocial work factors (e.g., work pressure, lack of control), which can cause stress, might also influence or be related to ergonomic factors such as force, repetition, and posture that have been identified as risk factors for WRMDs. In order to fully understand the etiology of WRMDs, it is important to examine both physical ergonomic and psychosocial work factors simultaneously. Smith and Carayon-Sainfort (1989) have proposed a model of the work system for stress management that provides a useful framework for conceptualizing the work-related factors that contribute to WRMDs. Practical applications of this research include practitioners taking into account psychosocial work factors and job stress in their efforts to reduce and control WRMDs.

INTRODUCTION

There has recently been interest in the role of occupational stress in the causation and aggravation of upper-extremity work-related musculoskeletal disorders (WRMDs; Moon, 1993; Moon & Sauter, 1996). Some believe that stress is the primary cause of the symptomology associated with many upper-extremity WRMDs (Hadler, 1990; Hadler, 1992). However, others, such as Smith (1984), Smith and Carayon (1996), and LeGrande (1993), believe that work organization and psychosocial factors at the workplace that might lead to psychological stress are important WRMD risks but do not preclude traditional ergonomic risk factors such as repetition, force, and posture.

Different terms have been used to describe WRMDs, such as cumulative trauma disorders, repetitive strain injuries, overuse injuries, and repetitive motion injuries. Putz-Anderson (1988) defined cumulative trauma disorders as a collection of health problems that have three characteristics. First, they are cumulative; that is, injuries develop over a long time as a result of repeated, continuous exposure of a particular body part to stressors. Second, the repeated, continuous exposure to stressors leads to trauma of tissues and joints. Third, WRMDs are physical ailments or abnormal conditions.

Putz-Anderson (1988) identified three types of upper-extremity WRMDs: tendon disorders (e.g., tendinitis), nerve disorders (e.g., carpal tunnel syndrome), and neurovascular disorders (e.g., thoracic outlet syndrome). The psychosocial and stress considerations in lower back pain have been examined by Feyer, Williamson, Mandiyk, DeSilva, and Healy (1992) and Bigos et al. (1991).

This paper focuses on disorders of the upper extremities (i.e., in the neck, shoulders, arms, and hands), which have not been examined in detail in relation to work organization and psychological stress.

Upper-extremity WRMDs have become more prevalent in the American workforce during

Address correspondence to Pascale Carayon, Department of Industrial Engineering, University of Wisconsin-Madison, 1513 University Avenue, Madison, WI 53706; carayon@ie.engr.wisc.edu. **HUMAN FACTORS**, Vol. 41, No. 4, December 1999, pp. 644–663.

the 1990s (Bureau of Labor Statistics [BLS], 1994). Recent interest by the Occupational Safety and Health Administration (OSHA) in the red meat packing industries (OSHA, 1990) and the increase in hand, wrist, shoulder, and neck problems accompanying the widespread use of computer-based technology (Gerr, Letz, & Landrigan, 1991) have highlighted this increase in upper-extremity WRMDs. Although occupational lower back injuries have been a substantial problem for decades, the magnitude of upper-extremity WRMDs has not been prominent until the last decade. Work-related musculoskeletal disorders are an increasing concern to occupational health and safety professionals, ergonomists, industrial engineers, employers, unions, and workers. The BLS has shown that all types of WRMDs have increased as a percentage of total occupational illnesses. In 1995, WRMDs associated with repeated trauma accounted for 308 000 cases, or 62% of new illness cases in private industry (BLS, 1999).

Work organization has been defined as the way in which work is organized, supervised, and carried out (Hagberg et al., 1995). Work organization can contribute to WRMD problems by specifying the nature of the work activities (variety or repetition), the extent of loads, the exposure to loads, the number and duration of actions, workstation design, tool and equipment design, and environmental features. The policies and procedures of a company can affect WRMD risk through the design of jobs and the definition of work-rest cycles; work pace (i.e., work pressure); the psychological climate regarding socialization, career, and job security; the level of employee training; the availability of assistance; and supervisory relations. All of these factors interact as a system to produce an overall stress load on a person that can lead to WRMDs (Smith & Carayon-Sainfort, 1989). Stress might logically have a role in upper-extremity WRMDs because such disorders are much more prevalent in occupations with features that produce job stress (i.e., short task cycles, monotony, low control, low content, and high work pace).

There are psycho-biological mechanisms that make a connection between job stress and WRMDs plausible and likely (Smith & Carayon, 1996; Sauter & Swanson, 1996). Psychological stress can lead to an increased physiological susceptibility to WRMDs by affecting hormonal, circulatory, and respiratory responses that exacerbate the influences of the traditional ergonomic risk factors (Blair, 1996; Landsbergis, Schnall, Warren, Pickering, & Schwartz, 1994; Schleifer & Ley, 1996). In addition, psychological stress can affect employee attitude, motivation, and behavior, which can lead to risky actions that increase WRMD risk (Smith & Carayon, 1996). This paper examines the possible physiological, psychological, and behavioral mechanisms for the relationship between job stress and upper extremity (i.e., neck, shoulders, arms, and hands) WRMDs. We emphasize the importance of work organization and job stress in the development, reporting, and experience of upper-extremity WRMDs.

Bongers, de Winter, Kompier, and Hildebrandt (1993) reviewed the existing research literature on psychosocial factors and musculoskeletal disease. Their review covers the back, neck/shoulders, and undifferentiated musculoskeletal symptoms. We focus on the upper-extremity musculoskeletal system; that is, the neck, shoulders, arms, and hands. First, we briefly review various theories of job stress and present a model of job stress. We then explain two mechanisms for the relationship between WRMDs and job stress: (a) a psychobiological mechanism and (b) psychological and behavioral reactions to stress. We subsequently highlight the importance of work organization in the development, experience, and reporting of WRMDs. Finally, we propose a conceptual model for examining work organization, job stress, and WRMDs.

THEORIES OF STRESS

In this section we review selected theories of stress uncritically. For a more complete review of stress theories, see, for example, Smith (1987) or Smith and Carayon-Sainfort (1989). The intent of this short review of selected theories of stress is to highlight the major characteristics of the stress process that can be used to explain potential links between job stress and upper-extremity WRMDs. It is not intended as an inclusive or complete review. The theories of stress are reviewed in relation to a job stress model.

The job stress model in Figure 1 is derived from theories of stress and the balance theory of job design and stress (Smith & Carayon-Sainfort, 1989). Work organization defines exposure to physical ergonomic risk factors and psychosocial risk factors, which in turn can lead to various stress reactions. When one is exposed to stressors over a prolonged period, these stress reactions can lead to different types of strain, including WRMDs. There is also a direct relationship between work organization and strain outcomes that represents the direct relationship between physical ergonomic risk factors and WRMDs, independent of stress reactions. Individual characteristics, such as personality, perceptions, coping, and health status, can influence the different elements of the model and the relationships among the elements of the model.

Psychosocial work factors have been defined as the subjective perceived aspects of the work organization that have an emotional connotation for workers and managers and that can result in stress and strain (Hagberg et al., 1995). Theories of stress have emphasized the psychological and perceptual mechanisms involved in the stress process. Lazarus (1974, 1977) suggested that physiological changes arise from a need for action resulting from emotions. The quality and intensity of the emotional reaction and its resultant physiological and behavioral changes depend on cognitive appraisal of the present or anticipated significance of the interaction with the environment or its threat to security and safety. Psychosocial work factors, such as quantitative workload, lack of job control, and job future ambiguity, can have short-term influences on stress reactions that can lead to different types of strain (Smith, 1987; Smith & Carayon, 1996). According to Lazarus (1974) and Lazarus and Folkman (1984), perceptions mediate the effect of work organization on stress reactions and strain. Objective (nonperceptual) work organization can also influence stress reactions in workers through direct physiological responses (Smith & Carayon-Sainfort, 1989). For instance, shiftwork has been shown to lead to various psychological and physical stress reactions and different strains, such as circadian rhythm disruption (Monk & Tepas, 1985).

Various work organization factors can influence stress reactions and strain. The stress reactions can be classified as psychological (e.g., adverse mood states, job dissatisfaction; Caplan, Cobb, French, Harrison, & Pinneau, 1975; Kahn, 1981; Lazarus, 1974, 1977), physiological (e.g., increased blood pressure, increased heart rate, increased catecholamine excretion, increased muscle tension; Frankenhaeuser &

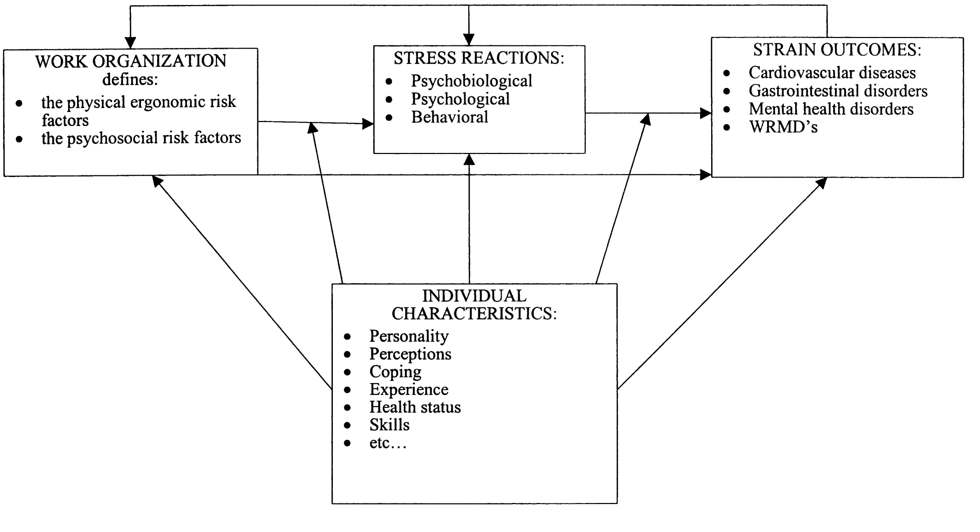

Figure 1. Model of job stress.

Gardell, 1976; Landsbergis et al., 1994; Levi, 1972; Selye, 1956; Westgaard, 1996), and behavioral (e.g., absenteeism, smoking, overeating, overuse of medication; Caplan et al., 1975; Lazarus, 1974, 1977; Levi, 1972). Selye's (1956) pioneering research defined the medical consequences of stress on the immune system, the gastrointestinal system, and the adrenal glands. That research also defined a cumulative process of wear and tear on the body that leads to disease and eventually death. Later theories of stress have included these physiological stress reactions as well as psychological and behavioral reactions (Lazarus, 1974, 1977; Levi, 1972).

If the individual is continuously exposed to a poor work organization, stress reactions can lead to different types of strain, such as hypertension, cardiovascular diseases, ulcers, neurosis, depression, alienation, and withdrawal (Caplan et al., 1975; Cooper & Marshall, 1976; Levi, 1972; Smith, 1987; Theorell & Karasek, 1996). Selye (1956) described the biological process by which the body attempts to adapt to some challenge by energy mobilization, disease fighting, and survival responses. Selye specified three stages that an organism undergoes in this process.

In the first stage, called the state of *alarm,* the body mobilizes biological defenses to resist the assault of an environmental demand. This stage is characterized by high levels of hormone production, energy release, muscle tension, and increased heart rate. The stage of *adaptation* is the second phase. In this stage the body's biological processes appear to return to normal, as it seems that the threat has been successfully dealt with. In the adaptation stage, the body is working very hard to maintain its homeostatic balance, which often carries a high physiological cost. In the third and final phase, called *exhaustion,* the biological integrity of the organism is placed in danger. This is because most primary biological systems begin to fail from the overwork of trying to adapt. Overload at the exhaustion stage can result in serious disability or death.

There are individual characteristics that influence the stress process (Lazarus, 1974, 1977; Levi, 1972). For instance, older individuals tend to be more satisfied with their job but are more likely to suffer from hypertension. Individual characteristics can also moderate the effect of work organization on stress reactions and the effect of stress reactions on strain (Cooper & Marshall, 1976; Smith & Carayon, 1996). For instance, when exposed to psychosocial work factors, Type-A behavior individuals tend to have more negative mood reactions than Type-B behavior individuals.

The job stress model also specifies *feedback loops* among stress reactions, strain, and work organization. Levi (1972) emphasized that the sequence of events described by the model is not a one-way process but, rather, is a cybernetic system with continuous feedback. Physiological stress responses and disease can affect the psychosocial stimuli as well as the individual's psychobiological program. These feedback loops are important in understanding why stress reactions and disease can act as stressors or mediate the effect of work organization on the individual.

In Figure 1, the arrows going from "Strain Outcomes" to "Stress Reactions" and "Work Organization" represent the feedback loops showing how strain can affect stress reactions and work organization. For instance, individuals with chronic diseases are more likely to report job dissatisfaction or adverse mood states. Stress reactions and strain can also affect individual perceptions of work organization. Through the feedback loops, strain can moderate or heighten the effect of work organization on stress reactions, such that individuals with chronic illness might be more sensitive to work organization and might react negatively to them. Coping behaviors aimed at dealing with the stress reactions and strain might be maladaptive and reinforce the individual's exposure or response to work organization (Lazarus, 1974, 1977).

PSYCHOBIOLOGICAL MECHANISM

When an individual is undergoing the psychological, physiological, and behavioral effects of job stress, there are changes in body chemistry that might increase the risk of WRMDs. Changes in the body include increased blood pressure, increased corticosteroids, an increase in peripheral neurotransmitters, an increase in muscle tension, less effective immune system response, and hyperventilation or overbreathing (Blair, 1996; Frankenhaeuser, 1986; Frankenhaeuser & Gardell, 1976; Karasek, Russell, & Theorell, 1982; Levi, 1972; Selye, 1956; Schleifer & Ley, 1996; Theorell & Karasek, 1996; Westgaard, 1996). Although it has long been known that these stress reactions can contribute to increased cardiovascular and psychological strain (Cooper & Marshall, 1976), we believe that they also can increase the risk of WRMDs.

An organism's basic reaction to external threat and internal psychological stress is to mobilize energy resources for defensive actions and to shut down response mechanisms that could compromise the organism's survival if injured (Selye, 1956). This reaction is controlled by the autonomic nervous system and is involuntary, with no cognitive perceptual aspects. Whereas some aspects of the autonomic nervous system can be consciously controlled (Engel, 1972), this reaction cannot. When this reaction occurs, there is less blood flow to the extremities. This protects the organism by reducing blood loss if an extremity is cut and bleeds, but it also means that there is the potential for less blood flow to the muscles of the extremities when it is most needed during repetitive work. The reduction in blood flow to the extremities could accelerate or exacerbate tissue damage during high workload and might precipitate the occurrence of upper-extremity WRMDs.

Several studies have shown a link between blood pressure and job stress. In particular, workload, work pressure, and lack of job control have been related to an increase in blood pressure. Rose, Jenkins, and Hurst (1978) found that workload was associated with increased systolic and diastolic blood pressure. In a cross-sectional study of 375 female hospital workers, Van Ameringen, Arsenault, and Dolan (1988) found that intrinsic pressure related to job content was correlated to increased standing diastolic blood pressure. The index of intrinsic pressure included a measure of quantitative workload (demands) and a measure of job participation (job control). Work pressure, such as having to meet deadlines, is a psychosocial work factor that might interact with both work hours and work pace to increase blood pressure (Friedman, Rosenman, & Carroll, 1958). In a study of 288 male blue-collar workers, Matthews, Cottingtom, Talbott, Kuller, and Siegel (1987) found that a limited opportunity for participating in decisions at work was related to increased diastolic blood pressure.

Longitudinal studies of job stress and blood pressure show that, over time, blood pressure increases are related to working conditions. In a one-year study of Japanese blue-collar workers, Kawakami, Haratani, Kaneko, and Araki (1989) found a relationship between blood pressure and technological change and complexity: Workers exposed to technological change, particularly a complex technology, had higher levels of blood pressure. In a six-year study of 340 Australian working men, Jenner, Puddey, Beilin, and Vandongen (1988) found that being a manual worker versus a professional worker affected blood pressure level: Manual workers had higher levels of blood pressure than professionals workers.

In a five-year study of 2634 Australian government employees, Chapman, Mandryk, Frommer, Edye, and Ferguson (1990) found a relationship between negative psychosocial work factors and blood pressure. Studies performed by researchers at the Cornell University Medical College further demonstrated the links among job strain, ambulatory blood pressure, and the risk for hypertension (Landsbergis et al., 1994; Schnall, Pieper, Schwartz, Karasek, & Schlussel, 1990), and between emotions (e.g., anger and anxiety) and increased blood pressure (James, Yee, Harshfield, Blank, & Pickering, 1986). High job strain, as defined by high workload and low job control, and negative emotions, such as anger and anxiety, were related to high blood pressure. High blood pressure might accelerate or exacerbate damage or degeneration of tissues in muscles, tendons, or nerves because the necessary nutrients do not reach the tissues when they are most needed, or there is increased pressure on the tissues (Armstrong et al., 1993), or both.

A third physiological reaction to stress is an increase in corticosteroids (Daleva, 1987; Finestone, 1986; Frankenhaeuser, 1986). Increased levels of corticosteroids, particularly cortisol, can lead to increased fluid retention in body tissues. This could be an important risk factor for carpal tunnel syndrome (CTS). Corticosteroid-induced fluid retention might be similar to the fluid retention in the extremities of women who are pregnant; this is believed to increase their risk of CTS (Stevens, Beard, O'Fallon, & Kurland, 1992; Voikt, Mueller, Farlinger, & Johnston, 1983). It is also analogous to the increased fluid production and tissue swelling attributable to repeated friction of the tendon body within the tendon sheath (Putz-Anderson, 1988). Excess fluid and tissue swelling can place pressure on and pinch the nerve(s) that can cause the paresthesia and pain associated with peripheral neuropathy.

Another biochemical reaction that occurs when an organism is under stress is an increase in peripheral neurotransmitters (particularly norepinephrine; Blair, 1996; Daleva, 1987; Finestone, 1986; Frankenhaeuser, 1986). This permits an individual to increase the rate of performance of motor activity because of an increased sensitivity of the synapses. Thus persons under acute psychological stress are often able to perform faster than when they are not under stress. This effect is often seen in athletic competition, in which stress motivates high performance. However, if this increased performance is sustained over a long period, it could lead to a substantially higher level of repetitive movements of the muscles, tendons, ligaments, and joints, which could be detrimental.

Another consideration related to physiological stress is the amount of tension in the muscles. With increased levels of norepinephrine, the tension in muscles has the potential to be greater, as does the extent of recruitment of the muscle fibers in performing an activity (Westgaard, 1996). This heightened muscle tension might be increased by adverse psychological moods such as anxiety or anger. Thus when a person is angry or frightened, the muscles are typically more tense. This can lead to heightened muscle tension and excessive muscular force when working. A few studies have suggested that increased muscle tension might be a mediating variable between psychosocial work factors and psychological stress on one hand, and musculoskeletal symptoms and disorders on the other (Theorell, Ringdahl-Harms, Ahlberg-Hulten, & Westin, 1991; Waersted, Bjørklund, & Westgaard, 1991; Weber, Fussler, O'Hanlon, Gierer, & Grandjean, 1980; Westgaard, 1996).

Theorell et al. (1991) studied the effects of psychosocial work factors on emotions, psychosomatic reactions, muscle tension, and musculoskeletal symptoms (back, neck, shoulders, and other joints) in a group of 207 workers in six occupations. Psychosocial work factors were related to negative emotions (e.g., worry), psychosomatic reactions (e.g., tiredness and sleep disturbance), and self-reported muscle tension. Muscle tension was strongly related to back, neck, and shoulder symptoms and to emotions. The authors argued that muscle tension might be an important pathway from psychosocially adverse job conditions to musculoskeletal symptoms.

Studies by Weber et al. (1980), Waersted et al. (1991), and Waersted and Westgaard (1996) suggest that there is psychologically mediated muscle tension through levels of task complexity. Waersted et al. (1991) examined the effect of varying task complexity by measuring the EMG activity of the trapezius muscles while participants performed two computer-based work tasks of different complexity with the same low level of postural strain. At the entire group level, the two tasks did not have a differential effect on muscle tension. However, a subgroup of participants consistently generated higher muscle tension during the complex task because of an increased mental effort. Weber et al. (1980) measured the effects of four different repetitive tasks – two that required discrimination and two that did not. With respect to muscle tension as measured by EMGs, the tasks requiring discrimination were accompanied by a higher neck tension compared with the nondiscrimination tasks.

At some point in the stress process, the organism is unable to continue responding normally, and exhaustion occurs (Selye, 1956). During this stress-induced exhaustion, the immune system is not able to function normally and thus cannot provide the typical resources for repairing damaged tissues. Studies by Vaernes et al. (1991) and Endresen et al. (1991) have shown that job stress, anxiety, and depression are correlated with changes in the immune system. Chronic exposure to ergonomic stressors while the organism is undergoing psychological stress might create microdamage that cannot be fully repaired and that can lead over time to permanent damage. Stress potentiates this process by limiting the ability of the immune system to respond positively for repairing tissue damaged by microtrauma.

Schleifer and Ley (1996) asserted the importance of breathing as a psychophysiological pathway through which work organization and psychosocial stress factors contribute to WRMDs in computer work. They presented a stress-induced hyperventilatory model of musculoskeletal problems that was based on two major premises.

First, under stressful conditions in computer work (e.g., boredom, fatigue), a chronic hyperventilation/overbreathing response occurs as a psychological stress effect that is characterized by reductions in the percent of CO_2 (PCO_2) in exhaled air. Second, there are well-defined psychophysiological effects of overbreathing, including increased neuronal excitability, heightened muscle tension and spasm, paresthesia, and a suppression of parasympathetic activity, coupled with a sympathetic dominance of the central nervous system, which results in the intensification of responses to catecholamines (Timmons & Ley, 1994).

PCO_2 is a psychophysiological indicator that can discriminate psychological stress effects in computer work from the physical effects of the job. There has been some confirmatory evidence of the stress-induced hyperventilatory model of WRMDs using measures of PCO_2. Specifically, increases in computer work stress have corresponded to reductions in end-tidal PCO_2 (Schleifer & Ley, 1994) and increases in right hand musculoskeletal discomfort while physical demands of the job remain constant (Schleifer, Ley, & Pan, 1995).

In conclusion, studies have shown that psychosocial work factors can initiate physiological changes in the body that might increase the risk for upper-extremity WRMDs. The physiological changes associated with psychosocial work factors include decreased blood flow to the extremities, increased blood pressure, increased corticosteroids, increased peripheral neurotransmitters, increased muscle tension, reduced effectiveness of immune system response, and hyperventilation/overbreathing.

PSYCHOLOGICAL AND BEHAVIORAL REACTIONS TO STRESS

A second major way in which stress can influence the occurrence of WRMDs is through its effects on a person's psychological and behavioral reactions. Thus stress can affect psychological moods, work behavior, coping style and actions, motivation to report injury, and motivation to seek treatment for a WRMD injury or symptoms of impending injury.

Upper-extremity WRMDs involve significant pain. In many cases, diagnosis of a disorder is based on the nature and extent of pain reported by the person. Stress might serve to increase the frequency of reporting upper-extremity pain because of a general increase in personal sensitivity to pain brought on by negative psychological moods. Increased pain or greater severity of pain has been related to psychological stress among patients with spinal cord injuries (Summers, Raphoff, Varghese, Porter, & Palmer, 1991), patients with low back pain (Atkinson, Slater, Grant, Patterson, & Garfin, 1988; Ryden, Lindal, Uden, & Hansson, 1985), and large samples of adults (Korff, Dworkin, Le Resche, & Kruger, 1988; Mechanic & Angel, 1987).

Theorell, Nordemar, Michelsen, and the Stockholm MUSIC I Study Group (1993) studied the relationship between psychosocial work factors and pain thresholds in a sample of 109 working men and women. A modified Stroop test with color words was used to induce psychological stress. Results showed that before the Stroop test, high job demands were associated with a high pain threshold. However, during the Stroop test, when psychological stress was high, it was observed that a low level of job decision latitude was related to a low pain threshold. Theorell et al. concluded that workers with chronically high levels of job demands have a high pain threshold and might ignore their bodies' warning signals. Therefore, they might be more likely to develop chronic musculoskeletal disorders. Conversely, under acute stress, workers with low job-decision latitude have a low pain threshold and might be more likely to experience and report pain-related symptoms of the musculoskeletal symptom. Thus pain that is really nonclinical and a normal part of the general adaptation process to work activity might be perceived by the person as much more significant because of heightened psychological stress. If this same person was not under psychological stress, the pain might not be perceived as significant and might go unreported.

Conway, Smith, Cahill, and LeGrande (1996) examined the relationship between the psychological mood state of tension-anxiety and musculoskeletal pain reported by office workers. Logistic regression analysis was performed to investigate the nature of the psychological tension of the worker and how this related to self-reports of musculoskeletal symptoms and disorder. Results supported a relationship between the psychological state of tension and musculoskeletal pain but did not support the relationship between psychological tension and sickness disability, showing that psychological stress was important in determining the level of pain experienced by individuals. In addition, a recent study of nurses in Belgium and the Netherlands concerning workload, psychosocial factors, musculoskeletal symptoms, and work loss suggested that nurses' reporting of musculoskeletal problems as well as the subsequent course of disability were influenced by psychosocial stressors at work (Burton et al., 1997). Many cases of reported pain end up being treated as WRMDs, and continued psychological stress at work might cause continued pain in spite of treatment(s). This might lead to more substantial treatment(s) over time, such as surgical interventions, when work organization interventions at the start could have played effective preventative or ameliorative roles.

A related issue is a social-psychological aspect of illness behavior (Mechanic, 1961). It is possible that people under psychological stress could develop specific physical symptoms (such as sore wrists) that would legitimate their general psychological discomfort and pain. Having pain in the wrists and fingers is an acceptable disorder, whereas feeling depressed is not considered as acceptable. Thus the effects of psychological disturbances might be reflected in physical disorders of the musculoskeletal system. This is akin to mass psychogenic illness (Colligan & Murphy, 1979) or psychosomatic disorders (Wolf, 1986), in which psychologically induced disturbances lead to physical impairment.

Mass psychogenic illness has been defined as "the collective occurrence of a set of physical symptoms and related beliefs among two or more individuals in the absence of an identifiable pathogen" (Colligan & Murphy, 1979, p. 82). The presence of a physical agent (e.g., odor) often serves as a trigger for the outbreak of physical symptoms. The illness is perceived as being caused by a physical agent, and the affected individual can then escape the hazardous environment (Colligan & Murphy, 1979).

A review of eight NIOSH investigations of unexplained physical symptoms showed that these symptoms were related to job and organizational characteristics that are well-known stressors (Schmitt, Colligan, & Fitzgerald, 1980). Individuals with low-pay, high-pressure, repetitive jobs are more likely to report these physical symptoms (Colligan & Murphy, 1979; Hall & Johnson, 1989; Schmitt et al., 1980). The emergence of upper-extremity WRMDs in the 1980s as an occupational disease has similarities to cases of mass psychogenic illness observed in the 1960s and 1970s. Like mass psychogenic illness, WRMDs have often been observed in low-pay, high-pressure, repetitive jobs (Hagberg, Morgenstern, & Kelsh, 1992; NIOSH, 1990, 1992; Putz-Anderson, 1988; Silverstein, Fine, & Armstrong, 1987). The outbreak of repetitive strain injuries in Australia is a good example of the similarity between the development of WRMDs and mass psychogenic illness (Kiesler & Finholt, 1988). WRMDs are physical disorders that are more socially acceptable than typical psychological stress reactions (Kiesler & Finholt, 1988).

In addition, the occurrence of WRMDs can act as a source of stress and trigger a stress reaction (see the feedback loop in Figure 1). This might be similar to the relationship that researchers have found between back pain and stress. Feuerstein, Carter, and Papciak (1987) conducted a prospective study of stress and recurrent low back pain. The purpose of the study was to determine whether patients with recurrent low back pain had a different pattern of mood fluctuations across days than did matched healthy controls and whether these mood states predicted or were predictors of pain occurrence. Patients with chronic low back pain reported higher levels of tension, anxiety, and fatigue and lower levels of vigor than did the healthy controls. No mood state was predictive of back pain onset, but fatigue increased 24 h following the onset of pain. Pain seemed to cause an increase in fatigue state, and this fatigue was superimposed on the chronic high levels of tension and anxiety. In a similar way, workers with WRMDs might experience psychological stress attributable to their physical problem. There might be a vicious circle of stress leading to WRMDs and vice versa.

Job stress can also affect the behavior of a person dealing with the work environment. For instance, someone who is stressed might become angry, and this could lead to using improper work methods, forceful work techniques (e.g., gripping a tool too tightly), or both. People under stress often develop poor attitudes and motivation about their job and about their personal health and well-being (Caplan et al., 1975; Kahn, 1981; Landy, 1992). In addition, they are more likely to be absent from work because of sickness (U.S. Department of Health, Education, and Welfare, 1979). Generally, maladaptive coping behaviors have been related to poor overall health, less energy, and greater general fatigue. This could make people more susceptible to injury or disease (Fitzgerald, 1992) and lead to a diminished capacity to work; both conditions increase the potential for WRMDs.

In summary, there are many potential ways that job stress can affect the risk of WRMDs. At the individual level, the first influence is the biophysiological stress reactions that can exacerbate the effects of physical strain, limit the ability of the body's defense and repair systems to deal with microtrauma, or both. The second influence is the effects of stress on the behavior of the individual that might increase reporting, increase exposures, or decrease the motivation to seek help. Some parallels exist between the occurrence of WRMDs and mass psychogenic illness. As a physical disorder, WRMDs might be more socially acceptable to report than psychological stress reactions. The third influence is the general sensitization of the individual psychologically and physically by exposure to job stress. This might lead to greater perceived pain and poorer overall health and vital capacity. For a summary of the possible mechanisms of the relationship between job stress and WRMDs, see Table 1.

The following section describes the link between work organization and WRMDs: (a) Work organization can influence job stress, which, as shown earlier, can affect the risk of WRMDs. (b) Work organization can determine or influence ergonomic risk factors of WRMDs.

TABLE 1: Possible Mechanisms between Job Stress and WRMDs

Type of Mechanism	Mechanism
Psychobiological	Changes in the body attributable to job stress – reduced blood flow to the extremities and to the muscles; increased blood pressure; increased corticosteroids, such as cortisol – fluid retention in body tissues; increase in peripheral neurotransmitters, such as norepinephrine – increased motor activity; increased muscle tension; reduced effectiveness of immune system response; hyperventilation/overbreathing, evidenced by reductions in end-tidal PCO_2
Psychological and behavioral	Nature and extent of pain reported by the person – increased pain, greater severity of pain; high pain threshold – body warning signals are ignored; legitimating discomfort and pain (see mass psychogenic illness and psychosomatic disorders); WRMDs as a source of stress; improper (stressful) work methods

WORK ORGANIZATION AND WRMDS

Work organization can be defined as the way in which work is structured, supervised, and processed. Work organization reflects the objective nature of the work process, whereas psychosocial work factors are the subjective aspects of work as perceived by workers and managers (Hagberg et al., 1995). Work organization dictates the extent of physical exposures at work in terms of workload, work pace, work schedule, work-rest cycle, design of equipment and workstations, product and materials design, and environmental design. Work organization also influences the psychosocial work environment, which has been related to job stress (Caplan et al., 1975; Smith, 1987).

The psychosocial work environment affects an individual's motivation to work safely, attitude toward personal health and safety, and willingness to seek health care. The work organization defines job requirements, personal skill requirements, extent and nature of personal training, and supervisory methods that influence the work methods used by employees. Table 2 contains a summary of the different types of relationships between work organization and WRMDs.

Studies have shown links among work organization, psychosocial work factors, and musculoskeletal disorders such as symptoms in the back, neck, and shoulders (Linton & Kamwendo, 1989; Theorell et al., 1991; Ursin, Endresen, & Ursin, 1988). Bongers et al. (1993) includes a review of these studies. Some empirical studies have examined work organization and upper-extremity WRMDs (Smith, Carayon, et al., 1992; Ferreira, Conceicão, & Saldiva, 1997; NIOSH, 1992). Smith, Carayon, et al. (1992) studied a group of 745 employees in telecommunications companies. The purpose of the study was to examine the link between job stress and electronic performance monitoring (EPM). Workers in monitored jobs reported higher levels of psychological stress, musculoskeletal symptoms, and psychosomatic symptoms than did workers in nonmonitored jobs. With regard to wrist symptoms, 51% of the monitored workers complained of sore or stiff wrists and 43% complained of loss of feeling in fingers or wrists, whereas the corresponding percentages for the nonmonitored workers were 24% and 27%.

The link between electronic performance monitoring and musculoskeletal discomfort was confirmed by a laboratory study of data entry operators (Schleifer, Galinsky, & Pan, 1996). Ferreira, Conceic‹o, and Saldiva (1997) retrospectively examined upper-extremity musculoskeletal disorder incidence in a group of customer service employees in the banking industry who also worked under conditions of EPM. Data included medical records and a reconstruction of work organization changes. Multiple linear regression analysis revealed an association between upper-extremity musculoskeletal disorder incidence and time pressure, (i.e., from a work standard that decreased

TABLE 2: Relationship between Work Organization and WRMDs

Type of Relationship	Relationship
Effect of work organization on job stress (through perceived psychosocial factors)	[see Table 1 for a description of the possible mechanisms] Psychosocial work factors: task stressors – job demands, lack of control, poor job content; organizational stressors – job future ambiguity, shiftwork; technology-related stressors – technology-related problems, insufficient training; environmental stressors – negative social environment
Effect of work organization on physical (ergonomic) factors	Nature of ergonomic factors – degree of repetitiveness, cycle time; strength of ergonomic factors – static jobs, machine pacing, no variation; exposure to ergonomic factors – work standards, work hours, pay system; exposure to poor physical environment – noise, lighting, temperature

acceptable work cycle time and rest/work schedule, for example through the introduction of 10-min rest breaks each hour).

NIOSH (1992) conducted a cross-sectional study of 533 telecommunications workers in five different jobs. Upper-extremity musculoskeletal disorders and working conditions were assessed using questionnaires and medical examinations. Separate analyses were conducted for each of the four upper-extremity body parts: neck, shoulder, elbow, and hands/wrists. Several measures of work organization were related to upper-extremity musculoskeletal disorders and symptoms. For instance, fear of being replaced by computers was related to increased neck and elbow symptoms, whereas high information-processing demands were related to increased neck and hands/wrists symptoms. Other work organization factors, such as surges in workload, lack of decision-making opportunities, high task variety, and lack of production standards, were also related to upper-extremity WRMDs (Hales et al., 1994).

A more recent cross-sectional survey study of 114 teleservice representatives also conducted by researchers at NIOSH showed further evidence of links among work organization, psychosocial factors, and WRMDs (Hoekstra, Hurrell, Swanson, & Tepper, 1996). Employees who reported a lack of control over their job tended to have a higher risk of back WRMDs, and perceived workload variability was associated with neck WRMDs.

A review of studies on musculoskeletal disease (in particular back, neck, and shoulder symptoms) and psychosocial factors suggested that monotonous work, high workload, time pressure, lack of job control, and lack of social support were related to musculoskeletal symptoms (Bongers et al., 1993). These factors as well as other psychosocial work factors could also be related to upper-extremity WRMDs.

Some recent studies have shown the importance of psychosocial work factors in influencing various types of musculoskeletal disorders. Smith, Conway, Cahill, and LeGrande (1996) and Conway et al. (1996) studied the effects of psychosocial aspects of working conditions on mood disturbances, musculoskeletal health complaints, and sickness absence for 396 state civil service employees in three agencies. They examined employee perceptions of several work organization factors, including workload, work pressure, participation, influence over work, job control, job future prospects, and social support. Some psychosocial work factors were found to have a direct, moderate relationship to musculoskeletal pain. Higher perceived workload was related to an increase in employees who reported back and hand pain. Lack of job control and low participation were related to an increase in employees who reported hand pain. Concern about job future was related to an increase in employees who reported back pain, and low social support was related to an increase in employees who reported elbow pain.

In a study of 150 VDT workers at a newspaper, Faucett and Rempel (1994) found a relationship between upper-extremity numbness and low decision latitude and low co-worker support. Lim (1994) suggested that psychological stress can play a mediating role between psychosocial work factors and WRMDs. In a study of a group of computer users, she showed some empirical support for this relationship. The psychosocial factors of high workload and low job control were related to high psychological stress, which in turn was related to high musculoskeletal discomfort.

Toomingas, Theorell, Michelsen, and Nordemar (1997) studied the associations between self-reported psychosocial work factors and musculoskeletal symptoms in a cross-sectional study of 358 workers in various occupations. Psychosocial work factors and musculoskeletal symptoms were recorded using a questionnaire, whereas musculoskeletal signs were obtained by physical examinations. Results indicated that the strongest associations were between poor psychosocial work conditions (i.e., low social support, high psychological demands, and high job strain) and both symptoms and signs of muscular tenderness in the neck and back. Other studies have found similar associations in a range of occupations, including health care professionals (Bru, Mykletun, & Svebak, 1996; Ahlberg-Hulten, Theorell, & Sigala, 1995) and computer users (Bergqvist, Wolgast, Nilsson, & Voss, 1995; Hovmark, Wollberg, & Nordqvist, 1996; Stephens & Smith, 1996).

A study by Kerr et al. (1997) showed that psychosocial work factors such as decision latitude and coworker support were important predictors of low back pain, even when adjusting for biomechanical factors. Similar results were reported by Skov, Borg, and Orhede (1996) in a group of salespeople and by Wahlstedt, Björkstén, and Edling (1997) in a group of 655 postal workers. Wahlsted, Björkstén, and Edling (1997) found that high psychological work demands were associated with symptoms in the lumbar region and that low social support at work was associated with symptoms in the neck-shoulders-thoracic region. Hoogendoorn and Bongers (1997) found that psychological demands were related to high upper-limb symptoms. Another study of computer users showed that occupational stress can have a detrimental effect on WRMDs that outweighs the effect of workstation design (Patterson, 1997).

Some longitudinal studies confirmed that psychosocial work factors can have an effect on musculoskeletal disorders over time. In a 10-year follow-up study of 902 blue- and white-collar workers, Leino and Hanninen (1995) found that the variables of social relationships/support and work content predicted changes in several measures of WRMDs. In a prospective study of unskilled female industrial workers, Björkstén, Boquist, Talbäck, and Edling (1997) found that as the condition of the psychosocial work environment worsened (e.g., less social support, more conflict with supervisors and other colleagues, poor cohesion at the workplace) over a period of three years, neck and shoulder pain increased. In a longitudinal study of computer users, Carayon, Haims, and Lim (1996) found that over a period of two years, an increase in psychological stress was related to an increase in hand-arm discomfort and upper-body discomfort.

Two possible effects of work organization on WRMDs have been identified. First, many work organization factors have been linked to stress reactions and strain. In the two previous sections, potential links among work organization, stress reactions, and WRMDs have been demonstrated. Second, work organization can influence ergonomic factors such as posture, repetition, and movement, which have been identified as risk factors of WRMDs.

Work organization can define or influence ergonomic risk factors of WRMDs, such as repetition, force, and posture (for a review of ergonomic risk factors of WRMDs, see Putz-Anderson, 1988). Work organization can define the nature of, strength of, and exposure time to these ergonomic risk factors by specifying how a job is to be carried out, establishing production levels, and defining pay structure. First, work organization can define the nature of ergonomic risk factors. Work organization might determine, for instance, the degree of repetitiveness of the job. In a highly fractionalized job, the worker tends to do the same tasks over and over, which produces repetition and boredom. The work organization also establishes cycle times through the design of tasks. Short cycle times and task repetitiveness define the repetition of motions. In a highly fractionalized job, the work organization defines that the worker will be exposed to high repetition, which is an ergonomic risk factor for WRMDs (Silverstein et al., 1987).

Second, work organization defines the strength of the ergonomic risk factors. A work organization that designs job tasks that do not encourage movement and do not allow workers to take minibreaks when needed might induce static awkward postures. For instance, machine-paced work is a work organization system in which workers have little freedom to influence the pace or standard operation of their work. Such a work system does not allow for any variation in work and usually does not give workers time to take minibreaks when needed (Smith, 1985).

Finally, work organization can define the exposure time to ergonomic risk factors. By setting work standards and pay schemes, managers set the pace at which a worker is supposed to work. This will then define the exposure time to certain risk factors. For example, if the worker is supposed to produce a certain number of products per period, this work standard will in turn define the duration of exposure to certain forces and postures. In addition, the number of hours of work are defined by management. Overtime, for instance, is a work organization factor that increases the duration of exposure to ergonomic risk factors. Such exposure might be particularly risky because of increased worker fatigue.

CONCEPTUAL FRAMEWORK FOR EXAMINING JOB STRESS AND WRMDS

A conceptual framework for examining job stress and WRMDs should have the following characteristics. First, the conceptual framework should give a significant role to job stress. Second, it should include physical ergonomic, psychosocial, and work organization factors as potential causes of WRMDs. These job factors can directly or indirectly influence WRMDs. Case studies have demonstrated the importance of examining both ergonomic and psychosocial work factors when trying to solve musculoskeletal problems (Hoekstra et al., 1996; Nordstrom, 1996; Rowe, 1987; Smith, 1994; Smith & Zehel, 1992; Wallin, 1987). Second, the model should allow for interactions among the various job factors and take into account the macroergonomic organizational aspects of work. Hendrick (1994) highlighted the need for a macroergonomic (systems) approach to better deal with upper-extremity WRMDs. Third, the conceptual framework should not be limited to only a few work organization factors. Many of the jobs linked to a high incidence of WRMDs are blue-collar jobs characterized by simplified, repetitive tasks. However, other jobs, such as those of reporters (NIOSH, 1990), that do not have these same characteristics have also shown a high prevalence of WRMDs.

Therefore, the conceptual framework should be holistic enough to include a wide variety of jobs and job factors. We believe that the balance theory of job design and stress (Smith & Carayon-Sainfort, 1989) can provide a useful framework for examining the relationships and interactions among work organization, job stress, and WRMDs.

According to Smith and Carayon-Sainfort (1989), stress results from an imbalance between various elements of the work system. This imbalance produces a "load" on the human response mechanisms that can produce adverse psychological and physiological reactions. The human response mechanisms, which include behavior, physiological reactions, and cognition, act to bring control over the environmental factors that create an imbalance. These efforts, coupled with an inability to achieve balance, produce an overloading of the response mechanisms that leads to mental and physical fatigue. Prolonged exposure and fatigue lead to strain and disease. This model emphasizes the definition of sources of occupational stress (psychosocial and physical work factors) that can then be manipulated to produce proper balance in the work system. These work factors can be categorized into one of the following elements of the work system: (a) the task, (b) the organizational context, (c) technology, (d) the physical and social environment, and (e) the individual.

Figure 2 displays the model of the work system. Each element of the work system can have positive and negative aspects that affect overall system balance. All negative aspects of the overall work system can seldom be eliminated. Therefore, if some negative aspects of the work system cannot be eliminated, one should consider how the other elements of the work system can be designed in order to compensate or balance out the influence of the negative aspects on the individual. This compensatory balance is important to consider when redesigning work systems and necessitates the consideration of all the elements of the system as well as their interactions. In order to evaluate the overall balance of the work system, one should measure the characteristics of the different elements of the work system and the effects on the individual

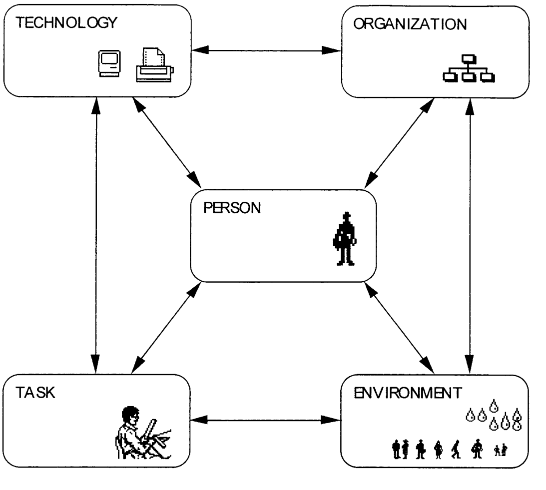

Figure 2. Model of the work system.

(i.e., stress reactions and strain outcomes; see, e.g., Carayon, 1994a).

In the task element, workload factors such as quantitative and qualitative underload and overload have been related to stress (Caplan et al., 1975; Frankenhaeuser & Gardell, 1976; Kalimo, Lindström, & Smith, 1997). Quantitative overload is a significant WRMD psychosocial work factor because it affects the extent of exposure and the frequency of upper-extremity actions. Repetitiveness is another psychosocial work factor that has been associated with physical problems such as musculoskeletal problems (Cox, 1985; Medsker & Campion, 1997; Salvendy & Smith, 1981), mental health disorders (Cox, 1985; Ferguson, 1973), and behavioral problems such as absenteeism (Cox, 1985).

Work pace is a very important workload factor. The speed or rate of work can influence worker well-being and physical health, especially when the speed is controlled by a machine. Machine-paced work tasks are more stressful than nonpaced tasks (Salvendy & Smith, 1981). Machine pacing is especially stressful because it is often characterized by quantitative overload, high work pressure, repetitiveness, and lack of control (Smith, 1985).

Ergonomic WRMD risk factors such as the frequency of repetitive motions and the duration of exposure are directly tied to the work pace and workload requirements (work standards) established by managers. Lack of participation (Caplan et al., 1975; Margolis, Kroes, & Quinn, 1974) and control (Karasek, 1979) in task activities can produce emotional problems and even increase the risk of cardiovascular disease, especially when accompanied by quantitative overload and lack of social support (Johnson, 1989; Karasek, 1979; Theorell & Karasek, 1996).

The organizational context in which work is done can often influence worker stress and health (Landy, 1992). Career considerations such as over- and underpromotion, status incongruence, and lack of job security have been linked to worker stress (Cooper & Marshall, 1976). Job future ambiguity has a stress connection for various occupations, such as factory and office work (Heaney, Israel, & House, 1994; Carayon-Sainfort, 1990). These organizational conditions might create a working climate of distrust, fear, and confusion that could lead employees to perceive more aches and pains and report more WRMDs. In particular, companies that have the potential for reductions in the labor force (layoff or job loss) might be more susceptible to employees' reporting more problems and more serious problems as an economic defense. Conversely, in a climate of distrust and fear, workers might not feel confident to report early signs of WRMDs, as they might fear losing their jobs. In such a context, there might be a high incidence of more serious WRMDs later.

Other organizational considerations include work schedule and overtime. Shiftwork has been shown to have negative mental and physical health consequences (Monk & Tepas, 1985; Tepas, Paley, & Popkin, 1997). Overtime influences exposure to WRMD risk factors at a time when the employee might be fatigued and unable to work at peak efficiency. This could lead employees to use risky work methods to remain on schedule. Overtime also increases the duration of exposure to risk factors. Caplan et al. (1975) found that unwanted overtime was a far greater problem than was the extent of overtime. Overtime might also have an indirect effect on worker stress and health because it reduces the amount of rest and recovery time, takes time away from relaxation with family and friends, and reduces time with sources of social support that can buffer stress.

Technological aspects of work might have inherent characteristics that make work stressful, such as physical and mental requirements, software "unfriendliness," and poor system performance (Carayon-Sainfort, 1992; Turner & Karasek, 1984). There is some evidence that computer technology can be a source of physical stresses, including visual and musculoskeletal problems (National Academy of Sciences, 1983; Smith, Carayon, et al., 1992; Smith & Cohen, 1997; Smith, Cohen, Stammerjohn, & Happ, 1981). The way in which technology is introduced might also influence worker stress and health and WRMDs (Smith & Carayon, 1995). For instance, when workers are not given enough time to become accustomed to technology, they might develop unhealthy work methods and postures. The change process associated with the implementation of new technology can produce feelings of lack of control and increased workload, which are both well-known sources of occupational stress (Kalimo et al., 1997; Smith, 1987; Smith & Conway, 1997). In addition, employees might fear that the new technology will eventually replace them and the need for their skills within the organization, which could induce feelings of decreased worth and job future uncertainty.

The social environment can be a source of social support that reduces worker stress (House, 1981; Johnson, 1989) but can also be a source of stress. Group pressure, negative social interaction, and relationships with upset clients are all potential psychosocial work factors (Kalimo et al., 1997; Landy, 1992; Smith, Carayon, et al., 1992). The physical environment can also be a source of physiological or psychological stress load. Several environmental factors have been identified as physical stressors: noise (Cohen, 1976; Glass & Singer, 1972; Crocker, 1997), lighting (Boyce, 1997; Cakir, Hart, & Stewart, 1978), and temperature (Konz, 1997; Rohles & Konz, 1987). Working in a physically stressful environment might increase one's susceptibility to other sources of stress. For instance, physical problems attributable to a stressful physical environment might induce psychological stress (Lim, Rogers, Smith, & Carayon-Sainfort, 1989).

In summary, a large variety of job and organizational factors have been shown to contribute to stress reactions and strain. Studies conducted at the University of Wisconsin-Madison have shown that a variety of work organization and psychosocial work factors can be related to WRMDs, especially among office workers and computer users (Carayon et al., 1996; Conway et al., 1996; Lim, 1994; Lim & Carayon, 1995; Smith, Conway, et al., 1996). Based on the previous discussion of the various ways in which the stress process can be linked to WRMDs, it is important to consider the whole work system, its characteristics, and its interactions with individual organizational members in defining the potential impact of work on the development of WRMDs.

The balance theory of Smith and Carayon-Sainfort (1989) provides an interesting framework for conceptualizing the job-related factors that can affect both the stress process and WRMDs. Longitudinal research or quasiexperimental research can provide additional information on the relationship between work organization and WRMDs. Most field research on this topic has been cross-sectional and correlational. Some longitudinal research has recently been reported, but more longitudinal research is warranted in order to understand the relationship between work organization and WRMDs over time (for a discussion of longitudinal studies of computer users, see Carayon, 1997). In addition, quasiexperimental research in which work organization is changed can provide useful information on the effectiveness of work organization interventions in dealing with WRMDs.

Studies conducted at the University of Wisconsin-Madison have also examined different mechanisms of the relationship between work organization and WRMDs, particularly among computer users and office workers. Lim (1994) tested the mediating role of psychological stress in the relationship between psychosocial work factors and musculoskeletal discomfort in a group of computer users. Conway (1999) examined the role of tension-anxiety in musculoskeletal discomfort. These studies examined the overall mediating role of psychological stress, as presented in the job stress model (see Figure 1). However, additional research is necessary to better understand the specific roles played by job stress in the relationship between work organization and WRMDs. For instance, the experimental research work conducted on muscle tension (see, e.g., Westgaard, 1996) and hyperventilation (see, e.g., Schleifer, Galinsky, et al., 1996) can provide important information on these mechanisms.

The balance theory and the job stress model discussed earlier emphasize the role of work organization in influencing WRMDs. Therefore, we recommend the implementation of sound work organization changes to deal with WRMDs. (Some specific suggestions for actions that employers can take to reduce the incidence of WRMDs in the workplace are discussed elsewhere; Carayon, 1994b; Haims & Carayon, 1998a, 1998b; Smith & Carayon, 1995.) Studies of work reorganization in office/computer work have been conducted at the University of

Wisconsin-Madison (Carayon, Haims, & Suh, 1997), and several studies have been completed recently (Derjani-Bayeh & Smith, 1999; Carayon, Haims, & Suh, 1998). Based on the balance theory's concept of work system, these intervention studies involve changes in both physical ergonomic and psychosocial aspects of work for a holistic systems approach.

Wahlstedt, Nygard, Kemmlert, Torgen, and Björkstén (1997) reported a reorganization in postal work that led to reduced musculoskeletal symptoms. The work reorganization consisted of improvements in teamwork, better physical facilities, and increased team responsibility. A comparison of conditions before and after the reorganization showed that physical ergonomic factors did not change but that psychosocial work factors improved: Psychological work demands decreased and social support improved. These improvements in the psychosocial work environment were accompanied by reductions in musculoskeletal symptoms in the shoulders and back.

Work reorganizations do not always lead to positive health effects, especially if the content and process of the change are not adequate (Carayon, 1994b). A reorganization of data entry work in a Swedish public agency did not lead to the benefits expected by the researchers (Aborg, Fernstrom, & Ericson, 1995). The workers were transferred to new working groups, but the amount of data entry work was not significantly reduced. As a consequence, muscle tension did not change, and neck-shoulder symptoms stayed at a very high level. The employees did not feel that they were sufficiently involved in the change process. This study demonstrates the importance of considering both the content and process of any work organization intervention if health benefits are to be expected (Carayon, 1994b; Carayon et al., 1997; Haims & Carayon, 1998a).

CONCLUSION

This discussion of stress and WRMDs has been presented to illustrate that there is some potential for work organization and psychosocial factors at work to contribute to upper-extremity WRMDs. Currently, however, there is not enough knowledge on the topic to know precisely what that role is. A substantial research literature needs to be developed before more definitive answers can be given. Yet it does seem very plausible that job stress can have a major influence on the development and treatment of upper-extremity WRMDs. Further theoretical developments are needed to conceptualize the links among work organization, job stress, and WRMDs. One theoretical approach was described in the latter section of the paper, based on the balance theory of job stress developed by Smith and Carayon-Sainfort (1989). In terms of practice, work organization intervention studies are needed to demonstrate the benefits of work reorganization. Work organization interventions at the University of Wisconsin-Madison are being conducted to serve this need (Derjani-Bayeh & Smith, 1999; Carayon et al., 1998).

Traditional ergonomic risk factors such as repetition, force, and posture have been postulated to contribute to WRMDs (Putz-Anderson, 1988; Silverstein et al., 1987). This paper has demonstrated that work organization factors and job stress might also play important roles in the development of WRMDs. Furthermore, we have shown that work organization and ergonomic factors interact or are related to each other in influencing WRMDs. Therefore, in order to fully understand the etiology of WRMDs and to prevent or control them, it is important to simultaneously examine physical ergonomic and psychosocial work factors in the context of work organization. The macroergonomic model of the work system developed by Smith and Carayon-Sainfort (1989) provides a useful framework to conceptualize the work-related factors that contribute to WRMDs and the relationship between job stress and WRMDs.

ACKNOWLEDGMENTS

The authors thank the reviewers and F. Thomas Eggemeier, associate editor of *Human Factors,* for their valuable comments. Funding for this research was provided by NIOSH (Center for Disease Control/NIOSH Cooperative Agreements U60/CCU512018-01 and U60/CCU512983-01; P.I.s: Michael J. Smith and Pascale Carayon).

REFERENCES

Aborg, C., Fernstrom, E., & Ericson, M. O. (1995). Psychosocial and physiological effects of reorganizing data-entry work – A longitudinal study. In A. Grieco, G. Molteni, B. Piccoli, & E. Occhipinti (Eds.), *Work with display units 94* (pp. 63–66). Amsterdam: Elsevier.

Ahlberg-Hulten, G. K., Theorell, T., & Sigala, F. (1995). Social support, job strain and musculoskeletal pain among female health care personnel. *Scandinavian Journal of Work Environment and Health, 21,* 435–439.

Armstrong, T. J., Buckle, P., Fine, L. J., Hagberg, M., Jonsson, B., Kilbom, A., Kudrinka, I. A., Silverstein, B. A., Sjogaard, G., & Viikari-Juntura, E. R. A. (1993). A conceptual model for work-related neck and upper-limb musculoskeletal disorders. *Scandinavian Journal of Work Environment and Health, 19*, 73–84.

Atkinson, J. H., Slater, M. A., Grant, I., Patterson, T. L., & Garfin, S. R. (1988). Depressed mood in chronic low back pain: Relationship with stressful life events. *Pain, 35*, 47–55.

Bergvist, U., Wolgast, E., Nilsson, B., & Voss, M. (1995). Musculoskeletal disorders among visual display terminal workers: Individual, ergonomic, and work organizational factors. *Ergonomics, 38*, 763–776.

Bigos, S. J., Battié, M. C., Spengler, D. M., Fisher, L. D., Fordyce, W. E., Hansson, T. H., Nachemson, A. L., & Wortley, M. D. (1991). A prospective study of work perceptions and psychosocial factors affecting the report of back injury. *Spine, 16*(1), 1–6.

Björkstén, M. G., Boquist, B., Talbäck, M., & Edling, C. (1997). A prospective study among unskilled female industrial workers with respect to neck- and shoulder ailments and environmental factors. In P. Seppälä, T. Luopajärvi, C.-L. Nygård, & M. Mattila (Eds.), *Proceedings of the 13th Triennial Congress of the International Ergonomics Association* (Vol. 4, pp. 22–24). Helsinki: Finnish Institute of Occupational Health.

Blair, S. J. (1996). Pathophysiology of cumulative trauma disorders: Some possible humoral and nervous system mechanisms. In S. D. Moon & S. L. Sauter (Eds.), *Beyond biomechanics: Psychosocial aspects of musculoskeletal disorders in office work* (pp. 91–97). London: Taylor & Francis.

Bongers, P. M., de Winter, C. R., Kompier, M. A., & Hildebrandt, B. H. (1993). Psychosocial factors at work and musculoskeletal disease: A review of the literature. *Scandinavian Journal of Work, Environment, and Health, 19*, 297–312.

Boyce, P. R. (1997). Illumination. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (2nd ed., pp. 858–890). New York: Wiley.

Bru, E., Mykletun, R. J., & Svebak, S. (1996). Work-related stress and musculoskeletal pain among female staff. *Work and Stress, 10*, 309–321.

Bureau of Labor Statistics (BLS). (1994). *BLS News – USDL-94-213*. Washington, DC: Bureau of Labor Statistics, U.S. Department of Labor.

Bureau of Labor Statistics (BLS). (1999). *Safety and health statistics: Workplace injuries and illnesses in 1995*. [Online news release]. Washington, D.C.: Bureau of Labor Statistics. Available http://stats.bls.gov/news.release/osh.nws.htm.

Burton, A. K., Symonds, T. L., Zinzen, E., Tillotson, K. M., Caboor, D., Van Roy, P., & Clarys, J. P. (1997). Is ergonomics intervention alone sufficient to limit musculoskeletal problems in nurses? *Occupational Medicine, 47*(1), 25–32.

Cakir, A., Hart, D. J., & Stewart, T. F. M. (1978). *The VDT manual.* Darmstadt, Germany: InceFry Research Association.

Caplan, R. D., Cobb, S., French, J. R. P., Harrison, R. V., & Pinneau, S. R. (1975). *Job demands and worker health.* Washington, DC: U.S. Government Printing Office.

Carayon, P. (1994a). Stressful jobs and non-stressful jobs: A cluster analysis of office jobs. *Ergonomics, 37*, 311–323.

Carayon, P. (1994b). A systems approach to reducing physical and psychological stress: Application in automated offices. In G. E. Bradley & H. W. Hendrick (Eds.), *Human factors in organizational design and management – IV* (pp. 733–738). Amsterdam: Elsevier.

Carayon, P. (1997). Temporal issues of quality of working life and stress in human-computer interaction. *International Journal of Human-Computer Interaction, 9*, 325–342.

Carayon, P., Haims, M. C., & Lim, S.-Y. (1996). Longitudinal study of ergonomic and psychosocial work stressors and musculoskeletal discomfort among computer users. In O. Brown & H. W. Hendrick (Eds.), *Human factors in organizational design and management – V* (pp. 273–278). Amsterdam: Elsevier.

Carayon, P., Haims, M. C., & Suh, H.-S. (1997). Work organization interventions for improving quality of working life. In P. Seppälä, T. Luopajärvi, C.-L. Nygård, & M. Mattila (Eds.), *Proceedings of the 13th Triennial Congress of the International Ergonomics Association* (Vol. 1, pp. 465–467). Helsinki: Finnish Institute of Occupational Health.

Carayon, P., Haims, M. C., & Suh, H. (1998). *Work organization interventions to prevent work-related musculoskeletal disorders in office and video display terminal work.* Madison, WI: University of Wisconsin-Madison.

Carayon-Sainfort, P. (1990). Job design predictors of stress in automated offices. *Behaviour and Information Technology, 9*(1), 3–16.

Carayon-Sainfort, P. (1992). The use of computers in offices: Impact on task characteristics and worker stress. *International Journal of Human-Computer Interaction, 4*, 245–261.

Chapman, A., Mandryk, J. A., Frommer, M. S., Edye, B. V., & Ferguson, D. A. (1990). Chronic perceived work stress and blood pressure among Australian government employees. *Scandinavian Journal of Work Environment and Health, 16*, 258–269.

Cohen, A. (1976). The influence of a company hearing conservation program on extra-auditory problems in workers. *Journal of Safety Research, 8*, 146–162.

Colligan, M., & Murphy, L. (1979). Mass psychogenic illness in organizational settings: An overview. *Journal of Occupational Psychology, 52*, 77–90.

Conway, F. T. (1999). Psychological mood state, psychosocial aspects of work, and musculoskeletal discomfort in intensive video display terminal (VDT) work. *International Journal of Human-Computer Interaction, 11,* 95–107.

Conway, F. T., Smith, M. J., Cahill, J., & LeGrande, D. (1996). Psychological mood state of tension and musculoskeletal pain. In O. Brown & H. W. Hendrick (Eds.), *Human factors in organizational design and management – V* (pp. 303–308). Amsterdam: Elsevier.

Cooper, C. L., & Cox, A. (1985). Occupational stress among word process operators. *Stress Medicine, 1*, 87–92.

Cooper, C. L., & Marshall, J. (1976). Occupational sources of stress: A review of the literature relating to coronary heart disease and mental ill health. *Journal of Occupational Psychology, 49*(1), 11–25.

Cox, T. (1985). Repetitive work: Occupational stress and health. In C. L. Cooper & M. J. Smith (Eds.), *Job stress and blue-collar work* (pp. 85–112). New York: Wiley.

Crocker, M. J. (1997). Noise. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (2nd ed., pp. 790–827). New York: Wiley.

Daleva, M. (1987). Metabolic and neurohormonal reactions to occupational stress. In R. Kalimo, M. A. El-Batawi, & C. L. Cooper (Eds.), *Psychosocial factors at work and their relation to health* (pp. 48–63). Geneva: World Health Organization.

Derjani-Bayeh, A., & Smith, M. J. (1999). Effect of physical ergonomics on VDT worker's health: A longitudinal intervention field study in a service organization. *International Journal of Human-Computer Interaction, 11,* 109–135.

Endresen, I. M., Ellertsen, B., Endresen, C., Hjelmen, A. M., Matre, R., & Ursin, H. (1991). Stress at work and psychological and immunological parameters in a group of Norwegian female bank employees. *Work and Stress, 5*, 217–227.

Engel, B. T. (1972). Operant conditioning of cardiac function: A status report. *Psychophysiology, 9*, 161–177.

Faucett, J., & Rempel, D. (1994). VDT-related musculoskeletal symptoms: Interactions between work posture and psychosocial work factors. *American Journal of Industrial Medicine, 26*, 597–612.

Ferguson, D. (1973). A study of occupational stress and health. *Ergonomics, 6*, 649–663.

Ferreira, M., Jr., Conceicão, G. M. S., & Saldiva, P. H. N. (1997). Work organization is significantly associated with upper extremity musculoskeletal disorders among employees engaged in interactive computer-telephone tasks of an international bank subsidiary in Sao Paulo, Brazil. *American Journal of Industrial Medicine, 31*, 468–473.

Feuerstein, M., Carter, R. L., & Papciak, A. S. (1987). A prospective analysis of stress and fatigue in recurrent low back pain. *Pain, 31*, 333–344.

Feyer, A.-M., Williamson, A., Mandiyk, H., DeSilva, I., & Healy, S. (1992). Role of psychosocial risk factors in work-related low back pain. *Scandinavian Journal of Work Environment and Health, 18*, 368–375.

Finestone, A. J. (1986). Neurohumoral mediators of emotional stress. In S. Wolf & A. J. Finestone (Eds.), *Occupational stress – Health and performance* (pp. 34–42). Littleton, MA: PSG Publishing Company.

Fitzgerald, T. E. (1992). Psychosocial aspects of work-related musculoskeletal disability. In J. C. Quick, L. R. Murphy, & J. J. J. Hurrell (Eds.), *Stress and well-being at work* (pp. 117–133). Washington, DC: American Psychological Association.

Frankenhaeuser, M. (1986). A psychobiological framework for research on human stress and coping. In M. H. Appley & R. Trumbull (Eds.), *Dynamics of stress – Physiological, psychological and social perspectives* (pp. 101–116). New York: Plenum.

Frankenhaeuser, M., & Gardell, B. (1976). Underload and overload in working life. A multidisciplinary approach. *Journal of Human Stress, 2*, 35–46.

Friedman, M., Rosenman, R. H., & Carroll, V. (1958). Changes in the serum cholesterol and blood clotting time in men subjected to cyclic variation of occupational stress. *Circulation*, 852–861.

Gerr, F., Letz, R., & Landrigan, P. J. (1991). Upper-extremity musculoskeletal disorders of occupational origin. *Annual Review of Public Health, 12*, 543–566.

Glass, D. C., & Singer, J. E. (1972). *Urban stress: Experiments on noise and social stressors.* New York: Academic.

Hadler, N. M. (1990). Cumulative trauma disorders – An iatrogenic concept. *Journal of Occupational Medicine, 32*(1), 38–41.

Hadler, N. M. (1992). Arm pain in the workplace – A small area analysis. *Journal of Occupational Medicine*, 113–119.

Hagberg, M., Morgenstern, H., & Kelsh, M. (1992). Impact of occupations and job tasks on the prevalence of carpal tunnel syndrome. *Scandinavian Journal of Work Environment and Health, 18*, 337–345.

Hagberg, M., Silverstein, B., Wells, R., Smith, M. J., Hendrick, H. W., Carayon, P., & Perusse, M. (1995). *Work-related musculoskeletal disorders (WMSDs): A reference book for prevention.* London: Taylor & Francis.

Haims, M. C., & Carayon, P. (1998a). Theory and practice for the implementation of "in-house," continuous improvement participatory ergonomic programs. *Applied Ergonomics, 29,* 461–472.

Haims, M. C., & Carayon, P. (1998b). Psychosocial factors case study: Work organization and WRMDs. In V. Rice (Ed.), *Ergonomics in health care and rehabilitation* (pp. 205–228). Boston: Butterworth Heinemann.

Hales, T. R., Sauter, S. L., Peterson, M. R., Fine, L. J., Putz-Anderson, V., Schleifer, L. R., Ochs, T. T., & Bernard, B. P. (1994). Musculoskeletal disorders among visual display terminal users in a telecommunications company. *Ergonomics, 37*, 1603–1621.

Hall, E. M., & Johnson, J. V. (1989). A case study of stress and mass psychogenic illness in industrial workers. *Journal of Occupational Medicine, 31*, 243–250.

Heaney, C. A., Israel, B. A., & House, J. S. (1994). Chronic job insecurity among automobile workers: Effects on job satisfaction and health. *Social Science Medicine, 38*, 1431–1437.

Hendrick, H. (1994). Macroergonomics as a preventative strategy in occupational health: An organizational level approach. In G. E. Bradley & H. W. Hendrick (Eds.), *Human factors in organizational design and management* (pp. 713–718). Amsterdam: Elsevier.

Hoekstra, E. J., Hurrell, J., Swanson, N. G., & Tepper, A. (1996). Ergonomic, job task, and psychosocial risk factors for work-related musculoskeletal disorders among teleservice center representatives. *International Journal of Human-Computer Interaction, 8*, 421–431.

Hoogendoorn, W. E., & Bongers, P. M. (1997). The Dutch prospective study on musculoskeletal disorders. In P. Seppälä, T. Luopajärvi, C.-L. Nygård, & M. Mattila (Eds.), *Proceedings of the 13th Triennial Congress of the International Ergonomics Association* (Vol. 4, pp. 46–48). Helsinki: Finnish Institute of Occupational Health.

House, J. (1981). *Work, stress and social support*. Reading, MA: Addison-Wesley.

Hovmark, S., Wollberg, E. F., & Nordqvist, S. (1996). A longitudinal study of health complaints in professional computer work: Effects of computer-aided design. *International Journal of Human-Computer Interaction, 8*, 401–420.

James, G. D., Yee, L. S., Harshfield, G. A., Blank, S. G., & Pickering, T. G. (1986). The influence of happiness, anger, and anxiety on the blood pressure of borderline hypertensives. *Psychosomatic Medicine, 48*, 502–508.

Jenner, D. A., Puddey, I. B., Beilin, L. J., & Vandongen, R. (1988). Lifestyle- and occupation-related changes in blood pressure over a six-year period in a cohort of working men. *Journal of Hypertension, 6*(suppl.4), 605–607.

Johnson, J. V. (1989). Control, collectivity and the psychosocial work environment. In S. L. Sauter, J. J. Hurrell, & C. L. Cooper (Eds.), *Job control and worker health* (pp. 55–74). New York: Wiley.

Kahn, R. (1981). *Work and health*. New York: Wiley.

Kalimo, R., Lindström, K., & Smith, M. J. (1997). Psychosocial approach in occupational health. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (2nd edition, pp. 1059–1084). New York: Wiley.

Karasek, R. A. (1979). Job demands, job decision latitude, and mental strain: Implications for job redesign. *Administrative Science Quarterly, 24*, 285–308.

Karasek, R. A., Russell, R. S., & Theorell, T. (1982). Physiology of stress and regeneration in job-related cardiovascular illness. *Journal of Human Stress, 8*(1), 29–42.

Kawakami, N., Haratani, T., Kaneko, T., & Araki, S. (1989). Perceived job-stress and blood pressure increase among Japanese blue collar workers: One-year follow-up study. *Industrial Health, 27*(2), 71–81.

Kerr, M. S., Shannon, H. S., Frank, J. W., Norman, R. W. K., Wells, R. P., Neumann, P., & Group, T. I. S. W. (1997). The relative importance of biomechanical and psychosocial risk factors in a case-control study of occupational low-back pain. In P. Seppälä, T. Luopajärvi, C.-L. Nygård, & M. Mattila (Eds.), *Proceedings of the 13th Triennial Congress of the International Ergonomics Association* (Vol. 4, pp. 64–65). Helsinki: Finnish Institute of Occupational Health.

Kiesler, S., & Finholt, T. (1988). The mystery of RSI. *American Psychologist, 43*, 1004–1015.

Konz, S. (1997). Toxicology and thermal comfort. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (2nd ed., pp. 891–908). New York: Wiley.

Korff, M. V., Dworkin, S. F., Le Resche, L., & Kruger, A. (1988). An epidemiologic comparison of pain complaints. *Pain, 32*, 173–183.

Landsbergis, P. A., Schnall, P. L., Warren, K., Pickering, T. G., & Schwartz, J. E. (1994). Association between ambulatory blood pressure and alternative formulations of job strain. *Scandinavian Journal of Work Environment and Health, 20*, 349–363.

Landy, F. J. (1992). *The psychology of work behavior*. Monterey, CA: Brooks/Cole.

Lazarus, R. S. (1974). Psychological stress and coping in adaptation and illness. *International Journal of Psychiatry in Medicine, 5*, 321–333.

Lazarus, R. S. (1977). Cognitive and coping processes in emotion. In A. Monat & R. S. Lazarus (Eds.), *Stress and coping – An anthology* (pp. 145–158). New York: Columbia University Press.

Lazarus, R. S., & Folkman, S. (1984). *Stress, appraisal and coping.* New York: Springer.

LeGrande, D. (1993). VDT repetitive motion health concerns in the U.S. telecommunications industry. In *Work with display units WWDU'92* (p. D-43, abstract). Berlin: Technische Universitat Berlin.

Leino, P. I., & Hanninen, V. (1995). Psychosocial factors at work in relation to back and limb disorders. *Scandinavian Journal of Work Environment and Health, 21,* 134–142.

Levi, L. (1972). Stress and distress in response to psychosocial stimuli. *Acta Medica Scandinavia, 191*(suppl. 528).

Lim, S.-Y., (1994). *An integrated approach to upper extremity musculoskeletal discomfort in the office environment: The role of psychosocial factors, psychological stress, and ergonomic risk factors*. Doctoral dissertation, University of Wisconsin-Madison, Madison, WI.

Lim, S.-Y. & Carayon, P. (1995). Psychosocial work factors and upper extremity musculoskeletal discomfort among office workers. In M. A. Grieco, E. Occhipitti, & B. Piccoli (Eds.), *Work with display units '94* (pp. 57–62). Amsterdam: Elsevier.

Lim, S.-Y., Rogers, K. S., Smith, M. J., & Carayon-Sainfort, P. (1989). A study of the direct and indirect effects of office ergonomics on psychological stress outcomes. In M. J. Smith & G. Salvendy (Eds.), *Work with computers: Organizational, management, stress and health aspects* (pp. 248–255). Amsterdam: Elsevier.

Linton, S. J., & Kamwendo, K. (1989). Risk factors in the psychosocial work environment for neck and shoulder pain in secretaries. *Journal of Occupational Medicine, 31*, 609–613.

Margolis, B., Kroes, W. M., & Quinn, R. (1974). Job stress: An unlisted occupational hazard. *Journal of Occupational Medicine, 16*, 654–661.

Matthews, K. A., Cottingtom, E. M., Talbott, E., Kuller, L. H., & Siegel, J. M. (1987). Stressful work conditions and diastolic blood pressure among blue collar factory workers. *American Journal of Epidemiology, 126*, 280–291.

Mechanic, D. (1961). Stress, illness behavior, and the sick role. *American Sociological Review, 26,* 51–58.

Mechanic, D., & Angel, R. J. (1987). Some factors associated with the report and evaluation of back pain. *Journal of Health and Social Behavior, 28*, 131–139.

Medsker, G. J., & Campion, M. A. (1997). Job and team design. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (2nd ed., pp. 450–489). New York: Wiley.

Monk, T. H., & Tepas, D. I. (1985). Shift work. In C. L. Cooper & M. J. Smith (Eds.), *Job stress and blue collar work* (pp. 65–84). New York: Wiley.

Moon, S. (1993). *Opening remarks.* Paper presented at the Workshop on Psychosocial Aspects of Cumulative Trauma Disorders, Duke University, Durham, NC.

Moon, S. D., & Sauter, S. L. (Eds.). (1996). *Beyond biomechanics: Psychosocial aspects of musculoskeletal disorders in office work.* London: Taylor & Francis.

National Academy of Sciences (NAS). (1983). *Video displays, work and vision*. Washington, DC: National Academy Press.

National Institute for Occupational Safety and Health (NIOSH). (1990). *Health hazard evaluation: Newsday, Inc.* (HETA 89-250-2046). Washington, DC: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control (CDC), NIOSH.

National Institute for Occupational Safety and Health (NIOSH). (1992). *Health hazard evaluation: US West Communications* (HETA 89-299-2230). Washington, DC: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, NIOSH.

Nordstrom, D. L. (1996*). A population based, case-control study of carpal tunnel syndrome.* Doctoral dissertation, University of Wisconsin-Madison, Madison, WI.

Occupational Safety and Health Administration (OSHA). (1990). *Ergonomics program management guidelines for meatpacking plants* (OSHA 3121). Washington, DC: U.S. Department of Health.

Patterson, K. (1997). Typing skill, exposure, and occupational stress as risk factors for neck and shoulder injury in non-secretarial computer users. In P. Seppälä, T. Luopajärvi, C.-L. Nygård, & M. Mattila (Eds.), *Proceedings of the 13th Triennial Congress of the International Ergonomics Association* (Vol. 4, pp. 96–98). Helsinki: Finnish Institute of Occupational Health.

Putz-Anderson, V. (Ed.). (1988). *Cumulative trauma disorders – A manual for musculoskeletal disease of the upper limbs*. London: Taylor & Francis.

Rohles, F. H., & Konz, S. A. (1987). Climate. In G. Salvendy (Ed.), *Handbook of human factors* (pp. 696–707). New York: Wiley.

Rose, R. M., Jenkins, C. D., & Hurst, M. W. (1978). *Air traffic controller health change study*. Washington, DC: U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Medicine.

Rowe, S. A. (1987). Management involvement – A key element in preventing musculoskeletal problems in visual display unit users in Australia. *Ergonomics, 30*, 367–372.

Ryden, O., Lindal, E., Uden, A., & Hansson, S. G. (1985). Differentiation of back pain patients using a pain questionnaire. *Scandinavian Journal of Rehabilitation Medicine, 17*, 155–161.

Salvendy, G., & Smith, M. J. (Eds.). (1981). *Machine-pacing and occupational stress*. London: Taylor & Francis.

Sauter, S. L., & Swanson, N. G. (1996). An ecological model of musculoskeletal disorders in office work. In S. L. Sauter & S. D. Moon (Eds.), *Beyond biomechanics: Psychosocial aspects of musculoskeletal disorders in office work* (pp. 3–21). London: Taylor & Francis.

Schleifer, L. M., Galinsky, T. L., & Pan, C. S. (1996). Mood disturbances and musculoskeletal discomfort: Effects of electronic performance monitoring under different levels of VDT data-entry performance. *International Journal of Human-Computer Interaction, 8*, 369–384.

Schleifer, L. M., & Ley, R. (1994). End-tidal CO_2 as an index of psychophysiological activity during VDT data-entry work and relaxation. *Ergonomics, 37*, 245–254.

Schleifer, L. M., & Ley, R. (1996). Macroergonomics, breathing, and musculoskeletal problems in computer work. In O. Brown & H. W. Hendrick (Eds.), *Human factors in organizational design and management – V* (pp. 261–266). Amsterdam: Elsevier.

Schleifer, L. M., Ley, R., & Pan, C. (1995, October). *Breathing and biomechanical indices of stress in mood disturbances and right-hand musculoskeletal discomfort in repetitive computer work*. Paper presented at the 2nd Annual Meeting of the International Society for the Advancement of Respiratory Physiology, Toronto.

Schmitt, N., Colligan, M. J., & Fitzgerald, M. (1980). Unexplained physical symptoms in eight organizations: Individual and organizational analyses. *Journal of Occupational Psychology, 53*, 305–317.

Schnall, P. L., Pieper, C., Schwartz, J. E., Karasek, R. A., & Schlussel, Y. (1990). The relationship between job-strain, workplace diastolic blood pressure and left ventricular mass index. *Journal of the American Medical Association, 263*, 1929–1935.

Selye, H. (1956). *The stress of life*. New York: McGraw-Hill.

Silverstein, B. A., Fine, L. J., & Armstrong, T. J. (1987). Occupational factors and carpal tunnel syndrome. *American Journal of Industrial Medicine, 11*, 343–358.

Skov, T., Borg, V., & Orhede, E. (1996). Psychosocial and physical risk factors for musculoskeletal disorders of the neck, shoulders, and lower back in salespeople. *Occupational and Environmental Medicine, 53,* 351–356.

Smith, M. J. (1984). Health issues in VDT work. In J. Sandelin, J. Bennett, & M. J. Smith (Eds.), *Video display terminals: Usability issues and health concerns*. Englewood Cliffs, NJ: Prentice-Hall.

Smith, M. J. (1985). Machine-paced work and stress. In C. L. Cooper & M. J. Smith (Eds.), *Job stress and blue-collar work* (pp. 51–64). New York: Wiley.

Smith, M. J. (1987). Occupational stress. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (pp. 844–860). New York: Wiley.

Smith, M. J. (1994, August). *A case study of a participatory ergonomics and safety program in a meat processing plant.* Paper presented at the 12th Triennal Congress of the International Ergonomics Conference, Toronto.

Smith, M. J., & Carayon, P. (1995). New technology, automation, and work organization: Stress problems and improved technology implementation strategies. *International Journal of Human Factors in Manufacturing, 5*(1), 99–116.

Smith, M. J., & Carayon, P. (1996). Work organization, stress, and cumulative trauma disorders. In S. D. Moon & S. L. Sauter (Eds.), *Beyond biomechanics: Psychosocial aspects of* *musculoskeletal disorders in office work* (pp. 23–42). London: Taylor & Francis.

Smith, M. J., Carayon, P., Sanders, K. J., Lim, S. Y., & LeGrande, D. (1992). Employee stress and health complaints in jobs with and without electronic performance monitoring. *Applied Ergonomics, 23*(1), 17–27.

Smith, M. J., & Carayon-Sainfort, P. (1989). A balance theory of job design for stress reduction. *International Journal of Industrial Ergonomics, 4*, 67–79.

Smith, M. J., & Cohen, W. J. (1997). Design of computer terminal workstations. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (2nd ed., pp. 1637–1688). New York: Wiley.

Smith, M. J., Cohen, B. G., Stammerjohn, I. W. J., & Happ, A. (1981). An investigation of health complaints and job stress in video display operations. *Human Factors, 23*, 387–400.

Smith, M. J., & Conway, F. T. (1997). Psychosocial aspects of computerized office work. In M. Helander, T. K. Landauer, & P. Prabhu (Eds.), *Handbook of human-computer interaction* (pp. 1497–1517). Amsterdam: Elsevier.

Smith, M. J., Conway, F. T., Cahill, J., & LeGrande, D. (1996). Psychosocial aspects of cumulative trauma. In O. Brown & H. W. Hendrick (Eds.), *Human factors in organizational design and management – V* (pp. 297–302). Amsterdam: Elsevier.

Smith, M. J., & Zehel, D. (1992). A stress reduction intervention programme for meat processors emphasizing job design and work organization. *Conditions of Work Digest, 11*, 204–213.

Stephens, C., & Smith, M. (1996). Occupational overuse syndrome and the effects of psychosocial stressors on keyboard users in the newspaper industry. *Work and Stress, 10*(2), 141–153.

Stevens, J. C., Beard, C. M., O'Fallon, W. M., & Kurland, L. T. (1992). Conditions associated with carpal tunnel syndrome. *Mayo Clinic Proceedings, 67*, 541–548.

Summers, J. D., Raphoff, M. A., Varghese, G., Porter, K., & Palmer, R. E. (1991). Psychosocial factors in chronic spinal cord injury pain. *Pain, 47*, 183–189.

Tepas, D. I., Paley, M. J., & Popkin, S. M. (1997). Work schedules and sustained performance. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (2nd ed., pp. 1021–1058). New York: Wiley.

Theorell, T., & Karasek, R. A. (1996). Current issues relating to psychosocial job strain and cardiovascular disease research. *Journal of Occupational Health Psychology, 1*(1), 9–26.

Theorell, T., Nordemar, R., Michelsen, H., & the Stockholm MUSIC I Study Group. (1993). Pain thresholds during standardized psychological stress in relation to perceived psychological work situation. *Journal of Psychosomatic Research, 37*, 299–305.

Theorell, T., Ringdahl-Harms, K., Ahlberg-Hulten, G., & Westin, B. (1991). Psychosocial job factors and symptoms from the locomotor system – A multicausal analysis. *Scandinavian Journal of Rehabilitation Medicine, 23*, 165–173.

Timmons, B. H., & Ley, R. (Eds.). (1994). *Behavioral and psychological approaches to breathing disorders*. New York: Plenum.

Toomingas, A., Theorell, T., Michelsen, H., & Nordemar, R. (1997). Associations between self-rated psychosocial work conditions and musculoskeletal symptoms and signs. *Scandinavian Journal of Work Environment and Health, 23*, 130–139.

Turner, J., & Karasek, R. A. (1984). Software ergonomics: Effects of computer application design parameters on operator task performance and health. *Ergonomics, 27*, 663–690.

U.S. Department of Health, Education and Welfare (USDHEW). (1979). *Healthy people – The Surgeon General's report on health promotion and disease prevention* (Publication No. 79-55071). Washington, DC: U.S. Government Printing Office.

Ursin, H., Endresen, I. M., & Ursin, G. (1988). Psychological factors and self-reports of muscle pain. *European Journal of Applied Physiology, 57*, 282–290.

Vaernes, R. J., Myhre, G., Aas, H., Homnes, T., Hansen, I., & Tonder, O. (1991). Relationships between stress, psychological factors, health and immune levels among military aviators. *Work and Stress, 5*(1), 5–16.

Van Ameringen, M. R., Arsenault, A., & Dolan, S. L. (1988). Intrinsic job stress and diastolic blood pressure among female hospital workers. *Journal of Occupational Medicine, 30*(2), 93–97.

Voikt, A. J., Mueller, J. C., Farlinger, D. E., & Johnston, R. U. (1983). Carpal tunnel syndrome in pregnancy. *Canadian Medical Association Journal, 128*, 277–281.

Waersted, M., Bjørklund, R., & Westgaard, R. H. (1991). Shoulder muscle tension induced by two VDT-based tasks of different complexity. *Ergonomics, 34*, 137–150.

Waersted, M., & Westgaard, R. H. (1996). Attention-related muscle activity in different body regions during VDU work with minimal physical activity. *Ergonomics, 39*, 661–676.

Wahlstedt, K., Björkstén, M. G., & Edling, C. (1997). Psychosocial work situation and musculoskeletal symptoms among postal workers. In P. Seppälä, T. Luopajärvi, C.-L. Nygård, & M. Mattila (Eds.), *Proceedings of the 13th Triennial Congress of the International Ergonomics Association* (Vol. 4, pp. 413–415). Helsinki: Finnish Institute of Occupational Health.

Wahlstedt, K., Nygard, C. H., Kemmlert, K., Torgen, M., & Björkstén, M. G. (1997). Effects of changes in work organization on health, work ability and musculoskeletal symptoms among town letter carriers. In P. Seppälä, T. Luopajärvi, C.-L. Nygård, & M. Mattila (Eds.), *Proceedings of the 13th Triennial Congress of the International Ergonomics Association* (Vol. 4, pp. 335–337). Helsinki: Finnish Institute of Occupational Health.

Wallin, L. (1987). Modification of work organization. *Ergonomics, 30*, 343–349.

Weber, A., Fussler, C., O'Hanlon, J. F., Gierer, R., & Grandjean, E. (1980). Psychophysiological effects of repetitive tasks. *Ergonomics, 23*, 1033–1046.

Westgaard, R. H. (1996). Effects of psychological demand and stress on neuromuscular function. In S. D. Moon & S. L. Sauter (Eds.), *Beyond biomechanics: Psychosocial aspects of musculoskeletal disorders in office work* (pp. 75–89). London: Taylor & Francis.

Wolf, S. (1986). Common disorders and grave disorders identified with occupational stress. In S. Wolf & A. J. Finestone (Eds.), *Occupational stress – Health and performance* (pp. 47–53). Littleton, MA: PSG Publishing Company.

Pascale Carayon is an associate professor of industrial engineering at the University of Wisconsin-Madison. She received her Ph.D. in industrial engineering from the University of Wisconsin-Madison in 1988.

Michael J. Smith is a professor of industrial engineering at the University of Wisconsin-Madison. He received his Ph.D. in psychology from the University of Wisconsin-Madison in 1973.

Marla C. Haims is a scientist at the Center for Quality and Productivity Improvement at the University of Wisconsin-Madison. She received her Ph.D in industrial engineering from the University of Wisconsin-Madison in 1999.

Date received: May 2, 1993
First revision received: September 27, 1994
Second revision received: February 25, 1998
Date accepted: July 12, 1999