CHAPTER 32

Cumulative Trauma Disorders of the Upper Extremities*

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CONTENTS

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32.1 INTRODUCTION

Upper extremity cumulative trauma disorders (CTDs) are regional musculoskeletal impairments that are associated with repetitive mechanical trauma occurring in the workplace [1]. CTDs of the upper extremities encompass a multitude of physical symptoms, pathology, and disability related to muscle tissue, ligaments, tendons, tendon sheaths, joints, and nerves. In various literature [2,3], CTDs have also been referred to as repeated trauma illness, repetitive motion injury, regional pain syndrome, repetitive strain injury (Australia), and occupational cervicobrachial disorder (Japan, Germany, and Scandinavia). They were once named according to the occupation or body part affected, for example, trigger finger, bricklayer's shoulder, pricer's palsy, mouse elbow, writer's cramp, stitcher's wrist, and carpenter's elbow [4]. These terms were descriptive but tended to minimize, even romanticize, the afflictions suffered by workers because of their jobs. The medical terms that are now more commonly used to describe CTDs (even among non-physicians) tend to add legitimacy to the symptoms that workers experience, and have likely increased workers' awareness regarding the work relatedness of overuse disorders.

Some authors (e.g., Ref. [5]) have advised against the use of inconsistent and imprecise terminology such as *cumulative trauma*, *repetitive strain injury*, and *overuse syndrome* in referring to musculoskeletal disorders (MSDs) of occupational origin. As such, the term work-related musculoskeletal disorders (WMSDs) may be more currently favored in the occupational health community; however, the term "cumulative trauma disorders" has been used interchangeably in this chapter. CTD is consistent with the terminology originally used in the first edition of this chapter, and the term distinguishes these conditions as a result of *chronic* overuse injury to the affected soft tissues. This contrasts with *acute* traumatic injuries, following the near instantaneous transfer of high energy, resulting in sprains, broken bones, cuts, lacerations, or amputations—which can also be viewed as "disorders" of the musculoskeletal system.

This chapter will address upper extremity CTDs (UECTDs) from an occupational ergonomics perspective, with emphasis on the approaches to identifying risk factors and characterizing a worker's exposure to them. The chapter will emphasize more recent work including job analysis and exposure assessment methods developed since the first edition of this text. The chapter will provide an update on MSD prevention programs (relevant to UECTDs) at Occupational Safety and Health Administration (OSHA) and

NIOSH (National Institute for Occupational Safety and Health), the U.S. federal agencies charged with protecting worker safety and health.

32.2 BACKGROUND AND SIGNIFICANCE TO OCCUPATIONAL ERGONOMICS

Ergonomics is a holistic approach to work layout that is rooted in achieving the best possible match of worker attributes and capabilities to the design and configuration of a work task. As such, application of ergonomic principles requires many considerations, including human anthropometry, biomechanics, work physiology, visual capabilities, and virtually every aspect of the physical environment [6]. Increasingly, there has been appreciation for the way that work is organized and prevention strategies that, in addition to physical stressors, also consider macro-ergonomic and psychosocial stressors and their influence on outcomes for WMSDs [7].

In industries where the work is physically demanding and many types of tools and powered equipment and machinery are in use, the classical approach of applying the many disciplines in the field of ergonomics is still necessary as a means to maximize worker health and efficiency. However, now that the health of workers is an issue in many workplaces that are quiet and environmentally controlled, the attention of ergonomic professionals (and indeed the overall perception of ergonomics by many people) has shifted from its historical multidisciplinary emphasis to the more limited area of WMSD prevention and control.

32.3 COMMON CTDs: THEIR SYMPTOMS AND DEVELOPMENT

UECTDs are classified as sprains, strains, inflammations, and irritations that affect tendon, muscle, nerve, vascular system, bursa, and bone/cartilage. This section presents an overview of the more common disorders to these various tissues. This is not intended to be a comprehensive description of these disorders. More detailed explanation of the diagnosis and clinical considerations of these conditions can be found in other references (e.g., Refs. [8,9]). A complete list of the MSDs that are considered to be related to work can be found in *The International Classification of Diseases*.

32.3.1 Tendon Disorders

The term *tendinitis* (or alternatively, *tendonitis*) generally refers to the inflammation of tendon, which may take on a variety of forms depending upon the location of the inflammation (see Figure 32.1). Insertional tendinitis occurs at the tendon-bone interface—a common example of which is observed as lateral epicondylitis ("tennis elbow") in which inflammation develops at the insertion of the extensor carpi radialis brevis muscle at the lateral epicondyle from repetitive forearm/elbow motions. *Peritendinitis* occurs in the more central region of the tendon, and *myotendinitis* is an inflammation at the muscle-tendon junction. *Tenosynovitis* refers to an inflammation in the sheath surrounding the tendon, which results in pain, swelling, and difficulty moving the affected joint. The inflammation results in a narrowing or stenosing of the tendon sheath, and tenosynovitis can lead to the condition of a trigger digit (trigger finger), in which a nodule forms on the tendon and inhibits normal gliding of the tendon within the sheath.

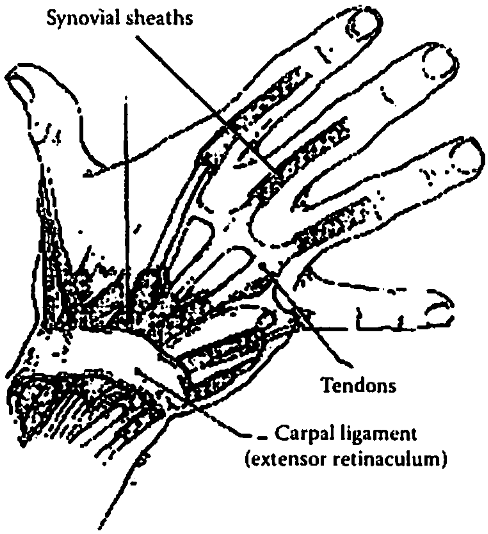


FIGURE 32.1 Dorsal (back) view of the hand showing the tendons and tendon sheaths. Also shown is the dorsal side of the carpal ligament.

De Quervain's syndrome describes a specific tenosynovitis of the tendon sheath of the thumb (abductor pollicis longus and extensor pollicis brevis). A modern day example of De Quervain's syndrome, illustrating how even contemporary technology can be implicated in the etiology of CTDs, is that coined in the lay media as "Blackberry Thumb" [10]. The seriousness of the musculoskeletal risk factors associated with the repetitive use of these hand-held mobile media devices was noted in the Consumer Education Alert released by The American Society of Hand Therapists [11].

32.3.2 Disorders of the Muscle

The term myalgia describes general tenderness and soreness of muscle tissue. Fibromyalgia is a condition characterized by chronic pain and a hypersensitivity to pressure on the affected tissue. Trigger points are localized points of spastic muscle, tender to the touch, that are surrounded by non-affected tissue. Pressure on these points elicits pain radiating along the extremity. Tension neck syndrome (TNS) is one of the more commonly reported myofascial syndromes, reported in a variety of occupations that involve prolonged static contraction of the trapezius (upper back) muscle for precision work involving visual task demands.

32.3.3 Nerve Disorders

Several nerve disorder syndromes are relevant to the discussion of UECTDs. A clinical syndrome refers to a conglomeration of concurrent symptoms that characterize a diagnosis. No upper limb nerve disorder seems to have received as much attention as carpal tunnel syndrome (CTS). CTS is a nerve entrapment syndrome in which the median nerve is compressed in the wrist cavity created by the carpal bones and the transverse carpal ligament (see Figure 32.2). Compression of the nerve in this tunnel results from an increase

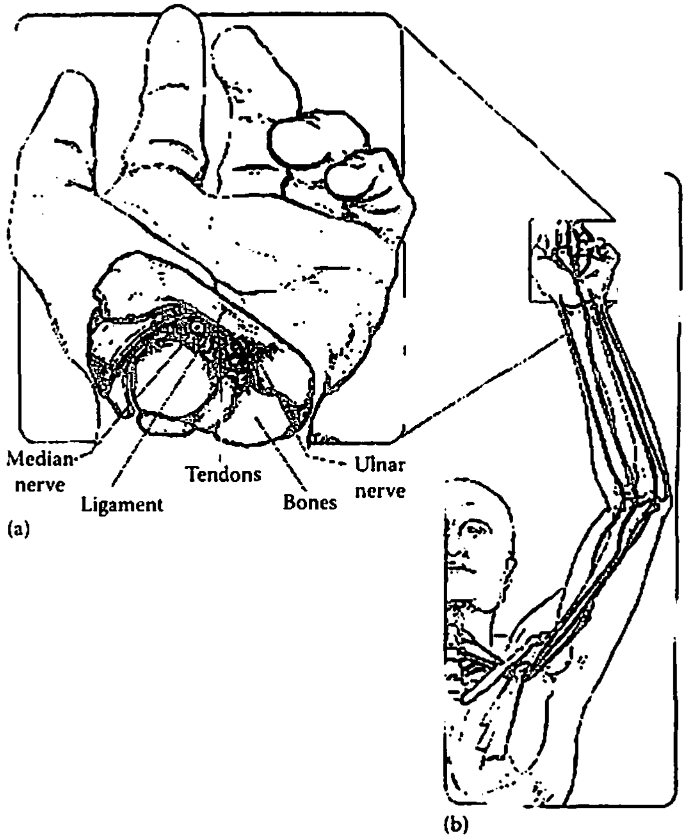


FIGURE 32.2 (a) Cross-sectional view of the carpal canal showing the tendons and nerves passing through it. (b) A full view of the three major nerves that originate in the neck and serve the arm and hand: the median, the ulnar, and the radial.

in the contents in this space and a number of other mechanical factors. Ischemia (restriction of blood supply to the tissue) and axonal demyelination (damage to the sheaths of the nerve) resulting from the compression contribute to the pathophysiology of CTS.

The ulnar and radial nerves are also subject to entrapment neuropathies. Ulnar nerve entrapment can occur at both the wrist (Guyon's canal syndrome) or the elbow (cubital tunnel syndrome). Radial tunnel syndrome is experienced as tenderness at the lateral aspect of the elbow and can mimic sensations of lateral epicondylitis. In the neck/shoulder region, thoracic outlet syndrome (TOS) is an umbrella term used to describe a number of entrapment neuropathies of the brachial plexus and/or the subclavian vessels as they pass through narrow passageways leading from the base of the neck to the armpit (See Figure 32.3). TOS is characterized by symptoms of numbness and tingling of the arm and hands and is commonly associated with occupational use involving overhead work and extensive elevation of the upper arm.

32.3.4 Vascular Disorders

A common vascular disorder of occupational origin is hand/arm vibration syndrome (HAVS). Use of vibrating powered hand tools exposes the user to a transfer of mechanical

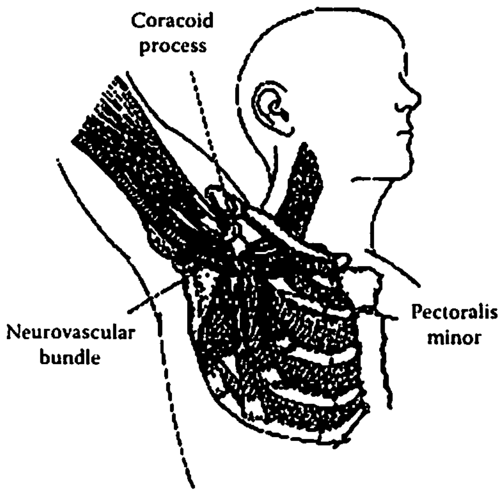


FIGURE 32.3 View of the nerves and blood vessels (neurovascular bundle) compressed between the neck and shoulder due to shoulder abduction (movement of the upper arm away from the body).

energy causing a vaso-constrictive response in the smooth muscle of the arterioles in the hands and fingers. This leads to a subsequent ischemic response and loss of blood flow to the digits. Classically known as "white finger" syndrome, the ischemia results in a blanching, or whitening, of the fingers. Raynaud's phenomenon describes bouts or "attacks" of white finger and painful sensations that are triggered by cold temperatures. Numbness and loss of precision function of the hand are symptoms of HAVS. Cold temperatures in combination with vibration exposure appear to magnify the risk for these disorders.

32.3.5 Bursa Disorders

Bursae are the fluid-filled sacs lined by synovial membrane that provide a cushion between bones and tendons and/or muscles around a joint. Bursae reduce friction and allow free joint movement. Bursitis refers to an inflammation of the synovial filled sacs and is commonly observed in the elbow (olecranon bursitis), shoulder (subacromial bursitis), and the knee (prepatellar bursitis). Other factors contributing to bursitis include blunt trauma, inflammatory disease, and infection.

32.3.6 Disorders of Bone and Cartilage

Osteoarthritis is a form of arthritis involving degenerative joint disease affecting articular cartilage and adjacent subchondral bone. It is believed to be precipitated or aggravated by joint overuse. Workplace factors such as pinch and power grip and impact loading have been identified as biomechanical risks for hand-wrist osteoarthritis [12].

Because many of the physical stresses attributed to UECTD development occur with regularity and in combination with high repetition in manual tasks in the workplace, they are known as work-related (or occupational) risk factors for CTDs. This term is not intended to diminish the multifactorial etiology, or cause, of CTDs but rather to emphasize the fact that work or occupation is a major factor in CTD development. The most common of the occupational upper extremity risk factors cited in the literature are the posture [13–16], the amount of muscular force associated with the activity [17,18], and the frequency or rate of repetition of the motions [19,20]. Working in cold environments [21,22] and using vibrating tools [23,24] are considered to increase the risk of CTDs.

The etiology and disease mechanisms associated with the development of CTDs are not fully understood, but it is believed that work activities which load the musculoskeletal system such as awkward posture, excessive force, and frequent repetition impose mechanical and physiological stress on the soft tissues of the upper extremity. For example, wrist deviations (flexion, extension, ulnar and radial deviation) shown in Figure 32.4 stretch the soft tissues across bones and ligaments, causing deformation of tendons and inflammation of tendon sheaths. Wrist deviations result in narrowing passageways that can place mechanical stress on tendons and entrap nerves. Nerve compression due to entrapment in a narrowed tunnel is thought to be one of the causes of CTS [25]. Under severe conditions, muscular force causes tendons and muscles to expand and swell, which can tear tissue and put pressure on nerves. Excessive repetitive movements can overcome the capacity of tendon sheaths to lubricate tendons and that of synovial membranes to lubricate joints. Motions and activities that comprise more than one or all of these occupational factors are more likely to result in the development of CTDs [26].

Regardless of the etiology and causation of UECTDs, there can be little doubt that affected individuals suffer in their physical, emotional, and social well-being. The financial burden of these conditions manifests at the establishment level through workers compensation costs and lost productivity. The financial burden on the individual has been shown to be even greater in terms of out of pocket medical expenses. Morse et al. [27] have shown that the majority of medical expenses for MSDs of the upper extremities are externalized from the workers' compensation system and that out of pocket costs to the afflicted worker averaged $500 per year. Lost productivity and quality of life in the home due to impaired function in activities of daily living

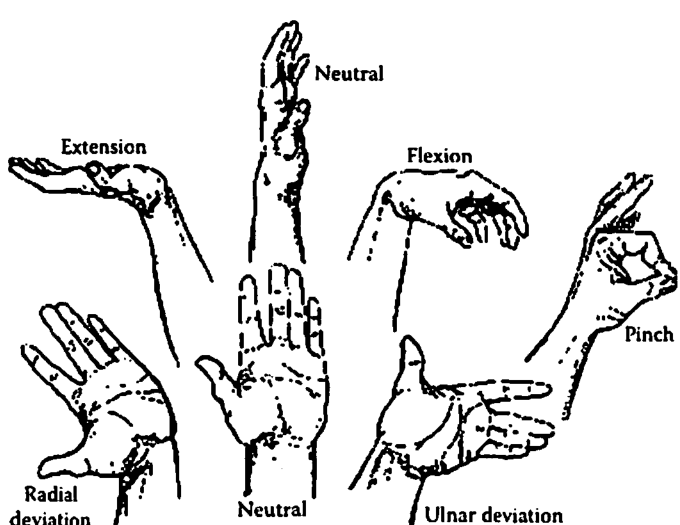


FIGURE 32.4 Deviated postures of the hand and wrist commonly associated with the development of UECTDs.

are difficult to calculate and are rarely included in these estimates. For these reasons UECTDs are of interest to the clinicians who treat the conditions, ergonomics specialists and engineers responsible for workspace layout and process design, and epidemiologists and public health practitioners in the surveillance and prevention of these disorders.

32.4 REVIEWS OF EVIDENCE FOR WORK RELATEDNESS

The term work-related musculoskeletal disorders (WMSDs) has emerged as the preferred terminology in the occupational health community. The "work relatedness" indicates that these conditions are precipitated by, or aggravated by, occupational activity. The World Health Organization [28] states that "...work-related diseases may be partially caused by adverse working conditions. They may be aggravated, accelerated, or exacerbated by workplace exposures, and they may impair working capacity." However, there are risk factors and physical exposures outside of the workplace that may contribute to the development of musculoskeletal symptoms and disorders, and similar MSDs exist in non-working populations. Thus, some have questioned the relative influence of workplace and non-workplace risk factors in the etiology of CTDs. This has motivated several significant epidemiologic efforts, published subsequent to the first edition of this text, to review the available body of evidence pertaining to the role of workplace exposures and non-occupational risk factors in the etiology of upper extremity WMSDs. Some of these major reviews are summarized here.

32.4.1 National Institute for Occupational Safety and Health: 1997 Review

In 1997, the NIOSH released a comprehensive review of the evidence of work relatedness of MSDs of the neck, upper extremity, and low back [29]. This publication, colloquially referred to as the "yellow book," reviewed over 600 published epidemiological studies to evaluate evidence for an association between physical work characteristics and WMSDs. Evidence was considered to be stronger for studies with participation rates greater than 70%, diagnoses made by physical examination, investigators blinded to case and/or exposure status, and exposure assessment conducted for the specific joint of interest and for the specific exposure being examined. Studies employing direct observation or physical measurements were given highest strength. The conclusion of this review was that sufficient evidence existed to link the physical work factors of force exertion, repetition, posture, and vibration to WMSDs of the upper extremity. Odds ratios and prevalence rate ratios were presented to describe the strength of association between risk factors and disorders. Table 32.1 is a general summary of the 1997 NIOSH review findings.

32.4.2 National Academy of Sciences/Institute of Medicine

In 1999, the National Academy of Sciences (NAS) and National Research Council (NRC) was charged with conducting a 2 year study of the contribution of workplace factors to MSDs of the low back and upper extremities [30]. This study came at the request of Congress to examine causation, diagnosis, and prevention of MSDs. The NAS committee identified 265 references related to work-related physical factors and upper extremity MSDs. Studies were reviewed based on criteria similar to that of the 1997 NIOSH review [29]. For UECTDs, 13 primary studies met the inclusion criteria and reported specific measures of exposure to

TABLE 32.1 Summary of NIOSH Findings in Its 1997 Review of Epidemiologic Studies of the WMSDs

Body Region/Disorder (No. of Studies)	Posture	Force	Repetition	Vibration	Notes
Shoulder (40)	Evidence	Insufficient evidence	Evidence	Insufficient evidence	
Neck and neck/ shoulder (24)	Strong evidence	Evidence	Evidence	Insufficient evidence	
Elbow (22)	Insufficient evidence	Evidence	Insufficient evidence		Strong evidence for combination of force w/posture or repetition
CTS (31)	Insufficient evidence	Evidence	Evidence	Evidence	Strong evidence for combination of force w/posture or repetition
Hand/wrist tendinitis (8)	Evidence	Evidence	Evidence	Evidence	Strong evidence for combination of force w/repetition
Hand-arm vibration syndrome (20)				Strong evidence	

Source: From Bernard, B., Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back, DHHS(NIOSH) Pub. No. 97-141, 1997.

physical risk factors of manual materials handling, repetition, force, vibration, and combinations of force and repetition, and repetition and cold. The majority of the associations evaluated in these studies were significant positive associations, particularly for manual materials handling, vibration, and the interaction of repetition and force. The NAS review also reported 29 studies with less-specific exposure assessment measures. These studies confirmed the importance of these risk factors in contributing to CTDs. The NAS report indicated that vibration, force, and repetition have been most strongly and consistently associated with UECTDs, with relative risks ranging from 2.3 to 84.5.

32.4.3 Non-Occupational Risk Factors

Manual activities outside of the workplace and other individual biological factors have been associated with the occurrence of CTDs. These have been referred to as *non-occupational* risk factors or *personal* risk factors. Examples are physically intensive pastimes and hobbies that have similar postural and repetitive muscular exertion patterns to work tasks, such as racquet sports, knitting, sewing, or the playing of video games and musical instruments [15]. Additionally, some biological and medical conditions that may predispose one to CTDs (particularly CTS) are rheumatoid arthritis, gout, acromegaly, diabetes, wrist size and shape, and hormonal factors (menopause, use of oral contraceptives, pregnancy, and gynecological surgery) [25,31,32]. As a number of these conditions are unique to women, women's risk of CTS may be elevated. Although it is generally reported that the incidence of CTS is greater among women than men [32], studies that have compared the rates of CTS among men and women performing the same work tasks have found no difference in CTS prevalence [18].

A few recent studies have emphasized the contribution of non-occupational factors in the development of certain MSDs of the upper extremity. In particular, CTS has been scrutinized in the debate over the relative contribution of occupational and non-occupational factors in its etiology. There seems to be little disagreement that non-occupational factors contribute to CTS risk. The controversy lies in the relative contribution of occupational and non-occupational factors and the importance of this determination in medical compensation systems and policy in regard to workplace health. Recent reviews by Lozano-Calderón et al. [33] and Palmer et al. [34] illustrate divergent viewpoints on the relative influence of occupational exposure in the etiology of CTS. Palmer et al. [34] reviewed 38 articles meeting their inclusion criteria (12 of these published after the release of the 1997 NIOSH review) and concluded that a substantial body of evidence supports the influence of highly repetitive wrist-hand work, especially when combined with forceful grip, in the causation of CTS. Lozano-Calderón et al. [33] reviewed 107 publications that evaluated the association between either occupational factors or biological (personal) factors and CTS. Included papers were scored by the investigators based on nine criteria integral to the Bradford Hill [35] analysis of epidemiologic studies. The authors reported that 66% of studies examining repetitive hand use showed correlation with CTS and that vibration and stressful manual work showed correlation in 70% and 46% of studies, respectively. However, the percentage of studies showing correlation between biological factors (anthropometry, gender, age, genetics) and CTS were higher. These authors further assert that the strength of epidemiologic evidence for causative association for biological factors outweighs that for occupational factors.

The conflicting conclusions of these review studies, drawn from the same body of literature, illustrate the complexity of the etiology of a disease such as CTS and the futility of implicating any single factor in its causation. As noted by Punnett and Wegman [36], the fact that occupational factors cannot account for a large proportion of the MSD burden in the general population does not negate a causal relationship between occupational factors and preventable MSD risks in the workplace. Regardless of the relative contribution of occupational and non-occupational factors to CTS, or any other UECTDs from which a worker may suffer, a primary prevention approach can be adopted. A worker's biological makeup is unalterable, whereas the design of the work processes and workplace which he or she interacts is frequently well within the control of the employer to modify.

32.5 UPDATE ON SURVEILLANCE DATA

Throughout the 1980s and early 1990s, the number and percentage of total occupational illness cases documented by the U.S. Bureau of Labor Statistics (BLS) as attributable to repeated trauma were steadily increasing, and appear to have peaked in the mid-1990s at about the time the first edition of *Occupational Ergonomics: Theory and Application* was published. The increasing trend prior to the mid-1990s may have been partly a result of the increased awareness of these disorders that occurred followed by a leveling-off period in the mid to late 1990s. The percentage of total occupational injury and illness cases attributed to repeated trauma (roughly 63%) remained fairly constant between the mid-1990s (first edition) and 2001 (see Figure 32.5). BLS data for 1992–2007 suggest that the number of musculoskeletal injuries and illnesses involving days away from work has declined markedly

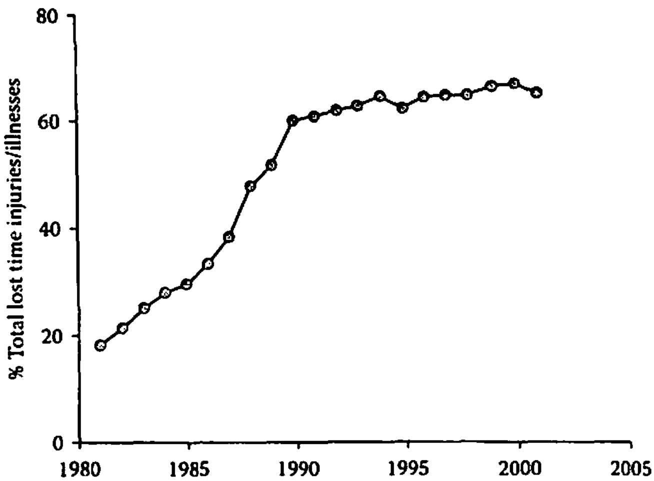


FIGURE 32.5 BLS data for repeated trauma illnesses (1981–2001) shown as a percentage of all lost time occupational injuries and illnesses.

from 782,000 to 335,000. However, significant changes in OSHA record keeping requirements occurring in 2001 have made it difficult to classify repeated trauma injury cases since 2001. Overall, MSDs still make up approximately 30% of the total non-fatal injuries and illnesses [37]. Specific to the upper extremity, the most recent BLS data [37] indicate that repetitive motion and overexertion cases that are not attributable to lifting reflect approximately 14% (162,000) of the 1.16 million illness and injury cases with lost days of work. CTS and tendinitis represent 3.6% and 1.1% of these 1.16 million cases, respectively.

It is commonly accepted that national U.S. injury and illness surveillance statistics underreport incidence of MSDs [38] and occupational illness overall [39]. As an example, BLS data indicate that CTS rates in the construction sector (per 10,000 workers) were 1.4, 1.7, 1.0, 1.3, and 0.4 for years 2003–2007. This is considerably lower than the 2.12% prevalence revealed for construction workers in the 1988 National Health Interview Survey (Occupational Health Supplement). Rosecrance et al. [40] found CTS rates in apprentice construction workers that were substantially higher—on the order of an 8.2% prevalence. It has been suggested that the changes in OSHA record keeping requirements in 2001 have resulted in lower reporting of MSDs. Friedman and Forst [41] have gone so far as to assert that 83% of the decline in occupational illness and injury observed since 2001 can be attributed to changes in the record keeping requirements.

Regardless of past trends, injury and illness rates suggest that workplace MSDs continue to be a public and occupational health problem. Their prevalence relative to all occupational injuries and illnesses is surpassed by their associated costs relative to other occupational injuries and illnesses. The total costs associated with WMSDs of the upper extremity are difficult to estimate and can include any combination of medical treatment and rehabilitation, lost time compensation, pensions for early retirement, or cost to rehire and to retrain new workers. In 1984, the American Academy of Orthopedic Surgeons conducted a study that included four data sources: (1) the National Health Interview Survey, (2) the National Hospital Discharge Survey, (3) the National Ambulatory Care

Survey, and (4) the Health and Nutrition Survey. The Academy estimated that annual direct costs for musculoskeletal injuries were in excess of $22 billion, indirect costs exceeded $5 billion, and total costs for all musculoskeletal conditions exceeded $65 billion [42]. Liberty Mutual, in their 2008 Workplace Safety Index, estimated direct workers' compensation costs in the United States. They cited a total workplace injury cost to industry of $48.6 billion, with $12.4 billion attributed to overexertion and $2.0 billion to repetitive motion. Liberty Mutual's report indicates that RMIs were associated with significant decline (down 35.3%) between 1998 and 2006. However, Rosenman et al. [43] found that only 25% of workers with work-related musculoskeletal conditions filed for workers' compensation. Thus, the true monetary burden of these disorders is underestimated by workers compensation claims.

In 1991, the Bureau of National Affairs [44] reported that a case of CTS could cost up to $30,000. In 2007, Washington state reported that the *average* CTS claim resulted in $22,000 in direct costs. Liberty Mutual Insurance Company indicated that one-third of workers' compensation (more than $10 billion in 1988) is paid out for RMIs in 1989, Liberty Mutual Insurance Company paid out an average of $5670 in workers' compensation for each case of CTD [44]. By 1991, that figure increased to $10,000 [45]. Between 1997 and 2005, the Washington State Workers' Compensation Fund accepted an average of 37,000 WMSD claims per year, with over $4 billion in direct costs resulting in more than 23.7 million lost work days [46]. The average compensable claims incidence rate of 92.9 per 10,000 full-time equivalents (FTEs) resulted in an average of 217 time-loss days per compensable claim. Of these compensable claims, 37% involved upper extremity MSDs.

It was noted in the first edition of this text that a fundamental reason for the increase in CTD incidence and cost through the 1980s and 1990s was the physical transformation of jobs and the workforce performing them. Technology advances such as the video display terminal in office environments, the laser scanner in grocery stores, and the bar code sorter in the post office have increased worker productivity, but have also increased the repetitive and stereotyped nature of jobs while depriving workers of the rest periods or microbreaks that were once inherent in most workstation designs. Many production jobs have been fragmented into repetitive, single-task activities that concentrate movements, forces, and mechanical stresses on small areas of the upper extremity. Such job designs are attractive to management and engineers because they simplify workplace layout, increase production output, facilitate work measurement, and minimize the amount of worker skill required. It is not surprising that some of the industries that have fragmented jobs the most have historically had the highest CTD rates, for example, meatpacking, poultry processing, and motor vehicle manufacturing.

32.6 JOB ANALYSIS AND EXPOSURE ASSESSMENT: METHODS FOR UECTDs

Since the first edition of this text, the discipline has seen a proliferation of checklist and observational-based methods for job analysis. These methods vary in their complexity and the resources required for their application. This section will focus on three approaches to job analysis and assessment of UECTD risk factors, classified as *risk factor* *checklists*, *systematic observational-based methods*, and *instrumentation-based measurement*. Checklist approaches afford the most rapid summary of the risk factors present, but with little sensitivity, precision, or ability to discriminate among exposure levels. Systematic observational-based approaches involve the application of a more rigorous structured assessment largely based on visual judgment of risk factor levels. They involve more analysis time than checklists, with the intent that the observed risk factor levels can be translated into an indication of risk for MSD outcomes. Direct-recording instrumentation-based measurement approaches are generally believed to be the most accurate methods of exposure assessment [47] but have not been widely adopted across the range of ergonomics practitioners.

32.6.1 Checklists

A number of ergonomic checklists have been developed in the last 15 years. Hamrick [48] described checklists as lists of risk factors or workplace conditions that help the user (or job analyst) ensure they have addressed areas of concern. Checklists generally serve as screening tools of jobs for the broad identification of risk factors and workplace conditions that are associated with increased risk for MSDs. They tend to require a lower level of user training and are well suited to situations where an analyst wishes to assess a large number of work processes to identify where ergonomic issues are present and to prioritize these work processes for more in-depth analysis. A common characteristic of checklists is that they rely on a dichotomous choice regarding the presence or absence of a physical risk factor, or whether or not the risk factor exceeds a certain threshold level. In general, checklist methods are applied in direct observation of the job, in contrast with more detailed event or time study-based methods that are more effectively applied during observation of a video recording of the job. The following are examples of checklist approaches appearing in the more recent literature on UECTD prevention.

Keyserling et al. [49] developed a two-page checklist addressing risk factors of repetitiveness, local contact stress, forceful exertions, awkward posture, and hand tool use. A qualitative rating scale was used to denote ergonomic exposures that are insignificant (denoted by a zero), moderate (denoted by a check mark), or substantial (denoted by a star). This checklist was applied to 335 jobs in an automotive facility as a screening tool, and the results were compared with those from an expert evaluation of a subset of 51 jobs. The checklist was designed to be highly sensitive to the presence of risk factors, and the comparison with experts' evaluations confirmed this intentional design bias. As an example, the checklist scores identified non-neutral wrist postures in 47 of the 51 jobs, whereas the expert evaluations identified this risk factor in 21 of the 51 jobs. All risk factors were more often shown to be present from the checklist results than by the expert evaluations. The authors suggest that a checklist should be designed for high sensitivity and a high rate of "false positives" in the screening phase. This way, few problematic jobs will be missed when jobs are screened and selected for more detailed ergonomic assessment.

PLIBEL [50] is a simple 17-item qualitative checklist that captures risk factors for all body regions. As with other checklists, many of the criteria are subjective—physical stresses pertaining to the upper extremity are particularly qualitative. (e.g., "Are tools and equipment unsuitably designed for the worker or the task?") The checklist questions are grouped according to relevant body regions so that specific risk factors for an injured body region can be identified. For the elbows, forearms, and hands, criteria include the presence of repetition of "similar work movement" and similar work movements beyond "comfortable reaching distance." Other criteria query the analyst about repetitive work with the forearm and hand performed with *twisting movements, forceful movements, uncomfortable hand positions, switches or keyboards,* and the presence of *awkward grasping of working materials or tools.*

The *Quick Exposure Checklist* (QEC) [51] combines assessments of risk factors made by the job analyst and the worker. Upper extremity stresses include the work height (categorized as below waist, chest height, above shoulder height); indication of a straight or bent wrist; whether arm movements are repeated infrequently, frequently, or very frequently; and the degree of repetitiveness of wrist hand motion patterns (three categories). Checklist criteria addressing the amount of force exertion required are directed to the worker and include the maximum weight handled (0–5, 6–10, and 11–20 kg) and the maximum force level exerted by one hand (<1 kg, 1–4 kg, >4 kg).

Washington State Department of Labor and Industries [52] developed an ergonomic assessment tool featuring "caution zone" and "hazard zone" checklists that identify upper extremity MSD risk factors. Jobs that exceed criteria for *caution zone* classification can be assessed against *hazard zone* criteria which represent greater severity. Criteria for the upper limb include working with the hands above the head more than two hours per day (caution), pinching an unsupported object weighing 2 or more pounds per hand, or pinching with 4 or more pounds of force more than 2 h per day (caution zone), and gripping unsupported objects weighing 10 lb or more per hand, or gripping with 10 lb or more force per hand, more than 2 h per day. Table 32.2 reproduces the checklist items for caution zone and hazard zone levels. Some of the mandatory language related to employer responsibilities for hazard zone jobs has been revised after the repeal of the Washington State Ergonomics Rule (see Section 32.7). The Washington state checklist is an example of one with more explicit quantitative criteria for the identification of UECTD risk factors.

The *ANSI A10.40* voluntary standard [53] is an industry-specific checklist developed for the construction industry. Because of this, there is an emphasis on the ergonomic aspects of the hand tools used. Checklist items address whether the tools are sharp and in good condition, whether the tools are very heavy or poorly balanced, or whether the tools vibrate excessively. Criteria address specific tools that must be used while in a difficult position (awkward posture), tools requiring bending of the wrists, and tools with poor handle design—defined as grips too big or too small, handles that are too short and dig into hands, handles with ridges that dig into hands, or slippery handles. Criteria also address the use of gloves and whether gloves make it hard to grip tools and whether there are other tools with a better design. A checklist item addresses repetitive motion through identification of tasks or jobs using the same motion dozens of times an hour for more than 1 h a day. The checklist addresses whether the number of repetitions can be reduced by job rotation or if rest breaks can be added. Awkward posture is addressed by identifying tasks or jobs that involve work above the shoulder or work at floor level or on the knees for more than 1 h per day and determining whether scaffolds, platforms, or other equipment cut down on the need

TABLE 32.2 Washington State Department of Labor and Industries Caution Zone Checklist

	Caution	Hazard
Awkward posture	Working with the hand(s) above the head, or elbow(s) above the shoulder, for *more than 2 h total per day*	*... more than 4 h total per day* Repeatedly raising the hand(s) above the head, or the elbow(s) above the shoulder(s) more than once per minute for more than 4 h total per day
High hand force	Pinching an unsupported object or objects weighing 2 or more pounds per hand, or pinching with a force of 4 or more pounds per hand, more than 2 h total per day	Pinching an unsupported object or objects weighing 2 or more pounds per hand, or pinching with a force of 4 or more pounds per hand: • Plus highly repetitive motion for more than 3 h total per day • Plus wrist flexion (30°)/extension (45°) or ulnar deviation (30°) for more than 3 h total per day • For more than 4 h total per day
	Gripping an unsupported object or objects weighing 10 or more pounds per hand, or gripping with a force of 10 or more pounds per hand, more than 2 h total per day	Gripping an unsupported object or objects weighing 10 or more pounds per hand, or gripping with a force of 10 or more pounds per hand: • Plus highly repetitive motion for 3 h total per day • Plus wrist flexion (30°)/extension (45°) or ulnar deviation (30°) for more than 3 h total per day • *For more than 4 h total per day*
Highly repetitive motion	Repeating the same motion with the neck, shoulders, elbows, wrists or hands (excluding keying activities) with little or no variation every few seconds, for more than 2 h total per day	Using the same motion with little or no variation every few seconds (excluding keying activities): • Plus high forceful exertions with the hands and wrist plus deviated wrist posture for more than 2 h total per day • *For more than 6 h total per day*
	Performing intensive keying more than 4 h total per day	Performing intensive keying: • Plus deviated wrist posture for more than 4 h total per day • *For more than 7 h total per day*
Repeated impact	Using the hand (heel/base of palm) or knee as a hammer more than 10 times per h, more than 2 h total per day	Using the hand as a hammer more than once per minute for more than 2 h per day total
Hand-arm vibration	Using impact wrenches, carpet strippers, chain saws, percussive tools (jack hammers, scalars, riveting or chipping hammers) or other hand tools that typically have high vibration levels more than 30 min total per day	
	Using grinders, sanders, jigsaws or other hand tools that typically have moderate vibration levels more than 2 h per day	

Note: The checklist items shown are those relevant to the upper extremity.

to work overhead. The checklist asks whether rotation or rest breaks can be used to reduce time in awkward postures.

A checklist with even greater emphasis on the design of the hand tools is the *California OSHA/NIOSH Hand Tool Checklist* [54]. This checklist was developed specifically for evaluating the non-powered hand tools used. The intent is to assist the worker in selecting the best tool for the particular job. The checklist includes quantitative and semi-quantitative criteria on the tool handle diameter, length, handle span, tool weight, handle surface contour, handle surface coating, and the degree to which the tool affords a neutral wrist posture of the user. A more detailed version of the checklist includes a proposed system for scoring tools on each of the checklist items to make comparisons among tools of the same type and function [55].

32.6.2 Systematic Observational-Based Methods

Checklists are generally inappropriate for quantifying the level of risk or likelihood of injury. The class of methods that exact more detail about risk factor levels and their translation to risk for MSDs of the upper extremities are referred to here as systematic observational-based methods. Since UECTD risk factors of awkward posture, repetitive motion, and the presence of hand force exertion (if not the force level) are visually observable, risk analysis approaches have been developed that are predicated on visual observation and estimation of these risk factors. Several structured approaches to observing and documenting these upper extremity risk factor levels have been developed and published since the first edition of this text. Analyses using these methods are frequently conducted from a video recording of the work so the analyst can view the work activity with slow motion, single frame advance, and pause capabilities.

This section will provide a brief summary of systematic observational-based methods for ergonomic assessment, emphasizing those specifically for UECTD risk factors and the whole-body methods that include the upper extremity. These methods have been summarized in other publications (e.g., Refs. [56,57]).

32.6.2.1 Specific to the Upper Extremity

Several observational-based measures have been developed specifically for the assessment of risk factors for the upper extremity, largely focusing on the hand and distal upper extremity. These are summarized in the following and in Table 32.3.

The *strain index* [58] is a method for evaluating physical risk factors and calculating a composite index that reflects the risk for distal UECTDs associated with a job. The strain index is suitable for jobs with relatively cyclic structure and is applicable to predict risk for CTDs of the elbow, forearm, wrist, and hand. Application of the strain index is based on observer judgment and rating of the intensity of exertion, duration of exertion, frequency of exertions (counted in efforts/min), hand/wrist posture, speed of work, and duration per day. Each of these variables is scaled with five rating levels and is assigned multipliers in proportion (inversely) to the rating. Exertion intensity scale levels are semantic (light, somewhat hard, hard, very hard, near maximal) but are anchored to quantitative percentages of maximum voluntary contraction (MVC) force. Conversely, the speed of work rating is a construct

TABLE 32.3 Summary of Four Observational-Based Job Analysis Methods Specifically for the Upper Extremities

Instrument (Primary Reference)	Posture	Force	Repetitive Motion
Strain index (Moore and Garg [58])	Wrist extension–5 categories (0°–10°, 11°–25°, 26°–40°, 41°–55°, >60°); wrist flexion–5 categories (0°–5°, 6°–15°, 16°–30°, 31°–50°, >50°); ulnar deviation–5 categories (0°–10°, 11°–15°, 16°–20°, 21°–25°, >25°)	Rating of intensity of exertion with 5 categories based on "% maximal strength" or rating of perceived exertion using the Borg CR-10 scale	Rating of "speed of work" based on how fast the worker is working relative to percentage of MTM-1 standard time
ACGIH TLV (ACGIH [79])	Deferred to professional judgment	Rating of peak force exertion (visual analog scale from 0 to 10)	Visual analog scale rating of HAL with verbal descriptors of activity level, or, identifying hand force duty cycle and rest periods and referring to table in ACGIH documentation
CTD risk index (Seth et al. [68])	Wrist angle used in equation to scale grip force capacity for types of grip/pinch Elbow flexion/extension–3 categories (>10° flex, 10° flex–30° ext, >30° ext); shoulder flexion–4 categories (0°–20°, 20°–45°, 45°–90°, >90°); shoulder abduction–4 categories (0°–30°, 30°–60°, 60°–90°, >90°)	Percentage of endurance capacity calculated as a function of the time posture is held, rest period, total working time, and load (estimated as %MVC)	Assumes 10,000 hand motions can be performed in one day. The number of allowable hand motions are reduced by other multipliers reflecting forcefulness and posture
OCRA (Colombini [64])	Wrist radial/ulnar deviation–2 categories; wrist flexion/extension–2 categories (0°–45°, >45°); forearm pronation/supination–2 categories; shoulder elevation–3 categories (0°–20°, 20°–60°, >60°)	The effort required to carry out a series of technical actions as expressed as a percentage of MVC	Assumes 30 technical actions per minutes are allowable. Allowable technical actions are reduced based on multipliers for posture and force

derived from MTM (methods-time measurement) predetermined motion time systems and can involve significant subjective judgment on the part of the analyst. Moore and Garg [58] recommend that video recordings of the job be observed as the basis for the analysis.

The *American Council of Governmental Industrial Hygienists* (ACGIH) *Threshold Limit Value for Hand Activity Level* (HAL TLV) is a voluntary standard established for the determination of safe levels of upper limb activity in work performed for greater than 4 h per day [59]. Similar to the strain index, the HAL TLV is appropriate for "mono-task" work, characterized by a predictable cyclic pattern of work elements and jobs that do not have variable task exposure. The HAL TLV does not account for posture of the upper limb, which is deferred to the professional judgment of the job analyst. Application of the HAL TLV involves determination of two parameters: the peak hand force and the hand activity level (HAL).

Peak hand force can be derived by a number of methods. If continuous time measurements of force are obtained, the 90th percentile level for hand/finger force is used—the rationale being that the finger transmits force between the work object and the tendons and muscles in the hand, wrist, and forearm [60]. In the absence of direct measurement, the peak force can be estimated by the analyst, or estimated by the worker. Psychophysical approaches such as the Borg CR-10 scale [61], visual analog scale percentage of maximal exertion, and force matching have been applied to obtain worker estimates of hand force level. Using the force-matching approach, the worker is asked to estimate and reproduce the force exertion on a hand dynamometer in a similar configuration as the work situation dictates. The reliability of the estimates are improved when arm/wrist/hand postures and grip contact conditions more closely approximate those of the actual task [62]. It is recommended that individual worker estimates of peak force be normalized to the strength capability of the worker population for the job.

The second parameter, the HAL, reflects the repetitive nature of the work in the exertion of force. HAL can be derived quantitatively from the observed exertion frequency and exertion recovery time using a look up table (see Table 32.4). The HAL can also be rated by the job analyst using a 10-point Visual Analog Scale with verbal anchors describing the frequency of hand motions and/or repeated exertions of hand force [63]. This is a less quantitative but more rapid approach as the analyst makes a judgment about the motions and repeated forceful task elements of the hand(s). The HAL and peak force are plotted on a graph and can be interpreted in relation to the threshold limit value (TLV) and a more conservative action level (AL) indicating the need to initiate some form of intervention. In the example described in Section 32.4 and illustrated in Figure 32.7 (bottom panel), the solid line represents the TLV, and the dashed line, the action limit.

The *Occupational Repetitive Actions* (OCRA) method [64,65] is based on a count of "technical actions"—a term used to describe micro-motion elements in the task that would be considered in a methods-time measurement analysis. Colombini [64] cited this approach as an advantage of the method asserting that it is easy to define and recognize technical actions and that company technicians, who are experienced in production organization, can relate to this construct. Technical actions can be described in terms of their frequency of occurrence, and the OCRA frequency constant for allowable technical

TABLE 32.4 Hand Activity Levels for Combinations of Exertion Frequency and Duty Cycle

Frequency	Duty Cycle %				
Exertions/s	0–20	20–40	40–60	60–80	80–100
0.125	1	1	—	—	—
0.25	2	2	3	—	—
0.5	3	4	5	5	6
1.0	4	5	5	6	7
2.0	—	5	6	7	8

Source: From American Conference of Governmental Industrial Hygienists (ACGIH), *Documentation of the TLVs and BEIs* (6th edn.), Cincinnati, OH: ACGIH Worldwide, 2005.

actions is 30 per min. The allowable number of technical actions is reduced by multipliers that account for force exertion, posture, recovery periods, and additional factors including exposure to vibration and/or cold, localized compression of soft tissues, requirements for accuracy, use of gloves, and hand impact. The formulation of the multipliers and how they reduce the allowable frequency of technical actions is similar to that of the original and revised NIOSH Lifting Equation [66,67]. The OCRA posture multiplier reduces the allowable technical actions based on theoretical assumptions about duration severity, which embodies both the duration of the awkward posture and its degree of deviation from neutral. Severity scores for the posture multiplier are proportional to the perceived discomfort elicited by the degree of postural deviation. Scaling of posture magnitude is based on 50% of the range of motion of the joints as shown in Table 32.3. The force multiplier decreases the frequency constant in proportion to the equivalent rating of perceived effort for the work cycle. Perceived effort is derived from the Borg CR-10 scale for perceived exertion.

A disadvantage of the OCRA method is that it can be time-consuming for complex tasks and multi-task jobs. Analyses almost always require observation of a video recording of the job and use of pause and single frame advance capabilities. A simplified OCRA checklist has subsequently been developed which reduces the complexity of the method.

The *CTD risk index* [68] has been less widely adopted, but is another detailed approach to assessing a job for increased risk for CTDs of the upper extremity. This method is based on established relationships between grip and pinch force capacity and wrist posture and discounting the allowable force exertion based on exertion duration and recovery periods. The method is somewhat similar to OCRA in that it involves counting the number of hand grip or pinch motions in a work cycle and converting this to a daily total based on the work cycle time and work duration. The daily count of grip motions is normalized to 10,000 per day, which is assumed to be the daily allowable limit. (The 10,000 daily hand motions compares favorably with 30 technical actions/minute, the frequency constant of the OCRA method.) The CTD risk index also adjusts the power and pinch grip force to the observed grip span based on equations expressing MVC capability as a function of grip span. The consideration given to posture in this method is complex and entails the use of equations for endurance capacity based on static hold time as a function of wrist posture, a recovery period between successive awkward postures, a point assignment for the severity of the postural magnitude (see Table 32.3), and the percentage MVC supported in relation to the 51 pound load constant of the NIOSH lifting guideline [66].

A simpler version of the CTD risk index appears in Niebel and Freivalds [69] which reduces the analysis complexity and time and is more appropriate for the evaluation of a larger number of jobs. This version calculates an index based on a hand motion frequency factor (relative to the allowable limit of 10,000 daily hand motions), a posture factor, a force factor, and miscellaneous factors such as use of gloves, presence of sharp edges on work contact surfaces, vibration exposure, and cold temperature.

32.6.2.2 Whole-Body Methods Including the Upper Extremity

In addition to the upper extremity–specific job analysis tools listed in the Section 32.6.2.1, other methods have been developed that assess ergonomic risk factors to all musculoskeletal regions.

These methods are classified here as *whole-body* methods. Ovako Working posture Analysis System (OWAS) and Rapid Upper Limb Assessment (RULA) were two of the earlier methods to be developed, and subsequent methods are similar in their approach. OWAS [70] emphasizes gross posture of the body and, in terms of the upper limbs, contains only a broad classification of shoulder posture based on the elevation of the elbows. The distal upper limb joints (elbows and wrists) are not considered in the OWAS method. The OWAS approach to the accumulation of points in proportion to the severity of individual body segment postures and the load handled has been adopted by other methods.

RULA is classified by many, including the original authors, as an upper limb assessment method [71]. It is grouped in this review with the whole-body methods because it includes assessment of lower extremity posture—unlike the methods discussed earlier that are specific to the upper extremity. RULA is largely based on an analysis of working posture. Severity points are accumulated for postures that deviate from neutral. There are four non-neutral posture categories for shoulder flexion/extension: >20° extension, 20° extension–45° flexion, 45°–90° flexion, >90° flexion, with one point added for abduction of the upper arm. There are two non-neutral categories for elbow flexion (0°–60°, >100°) and two non-neutral categories of wrist flexion/extension (beyond neutral to 15° flex/ext, >15° flex or ext) with one point added for a "deviated or twisted" wrist. Posture severity is classified according to the posture held for the longest duration or for which the highest loading occurs. Force exertion and repetition are established by classifying resistance or load handled according to levels of less than 2 kg, 2–10 kg, or greater than 10 kg and whether the load is static, intermittent, or repeated. The RULA grand score is derived from an accumulation of points for the severity of upper limb stresses in combination with the severity of neck, trunk, and leg stresses.

The Rapid Entire Body Assessment (REBA) [72] is a variation of RULA developed for application in the health care industry. REBA adds load coupling in a manner similar to the revised NIOSH Lifting Equation [66]. REBA is largely postural based, and the scoring is similar to that of RULA in the translation of the score to a risk or action level.

Loading on the Upper Body Assessment (LUBA) [73] differs from the previously described approaches in the rationale for assigning severity to postural deviation. LUBA posture severity scaling was based on a psychophysical study of perceived postural discomfort [74] and matching the ratio of severity scores to the ratio of discomfort levels associated with various postures. The LUBA method considers only posture, and its application considers only the psychophysical perception of postural discomfort as the determinant of acceptable working postures.

PATH [75,76] differs from the methods discussed earlier in that it is a work sampling-based approach that was developed more specifically for construction work, in which the postures, motions, and forces exerted are variable and non-cyclic in nature. Assessments using PATH consider postures (P), activities (A), tools (T), and handling (H) inherent in a number of construction trades. Because construction work is typically characterized by variable, non-cyclic patterns of exposure, jobs cannot be analyzed at the unit of a short duration fundamental work cycle. PATH relies on fixed-interval observations in real-time. PATH emphasizes trunk and leg posture in the framework of the OWAS method, but does include shoulder posture stresses when work is performed with elbows above shoulder height. Because the validity of work sampling increases when a large number of observations are included, the authors recommend that PATH observations be made in intervals less than 60 s.

32.6.2.3 *Validity Considerations*

Several studies have examined upper extremity observational-based job analysis methods for their predictive and/or external validity, which describe how well they predict the prevalence of upper extremity MSDs. Knox and Moore [77] assessed 28 jobs in a turkey processing plant with classifications of "hazardous" or "safe" based on a strain index score of 5 as a cutoff. Presence of MSD outcomes, or morbidity classification, was based on a physician review of OSHA 200 injury logs. Sensitivity, a measure of the percentage of jobs that are correctly predicted as being associated with morbidity, was reported as 0.91; specificity, a measure of the percentage of jobs correctly predicted as being associated with no morbidity, was reported as 0.83. An odds ratio of 50.0 was reported. Rucker and Moore [78] reported even stronger predictive validity of the strain index when applied in two manufacturing facilities.

In a larger cross-sectional study of 352 workers across three manufacturing facilities, Latko et al. [63] reported modest odds ratios for hand outcomes when considering only the ACGIH HAL rating as an exposure metric. Collapsing the continuous HAL scale into three categories (low, medium, high) resulted in odds ratios up to 3.33 (1.27–8.26, 95% CI) for the low vs. high category comparison in predicting tendinitis. The jobs evaluated in this study exhibited little variability in exposure level for hand posture or force exertion. Thus, the contribution of these stressors in predicting hand outcomes could not be determined. Franzblau et al. [79] conducted an even larger cross-sectional study with over 900 workers at 7 facilities to assess the predictive validity of the ACGIH TLV. TLV categories were positively associated with elbow/forearm tendonitis and CTS; however, sensitivity and specificity were shown to be modest for most outcomes, with the former being less than 0.6 for all outcomes. The authors noted a high prevalence of reported symptoms in jobs below the TLV action limit.

In a recent study of 567 workers, Spielholz et al. [80] evaluated the predictive validity of both the strain index and ACGIH TLV. The risk factors that were related to disorders of the dominant distal upper extremities were peak and most common hand force, a strain index greater than 7.0 vs. less than 3.0 (odds ratio = 2.33), and strain index greater than 7.0 vs. less than 7.0. For the nondominant hand, the HAL category less than 4.0 vs. HAL category greater than 4.0 (OR = 2.81) was the only significant relationship with health outcomes. The Spielholz et al. [80] study suggests that a strain index of 7 achieves roughly equivalent sensitivity and specificity in predicting MSD outcomes and was associated with significant odds ratios for distal upper extremity outcomes in the dominant hand. This finding is in line with the recommendations of Rucker and Moore [78] that the criterion value of 5.0 might be increased—perhaps to as high as 9.0, for manufacturing jobs. Spileholz et al. [80] reported some differences between the strain index and ACGIH TLV in terms of risk category classification (safe, action level, and hazardous zones). With a strain index of 7.0 as the hazard zone threshold, and 3.0 as the safe zone threshold, the strain index classified more jobs in the hazard zone than the ACGIH TLV, and that the TLV categorized more jobs as safe. This group [81] has suggested that the strain index may be more protective, particularly for jobs in the median exposure levels, and that when combining data from multiple studies, agreement in risk classification between the two methods was 75%. The studies of Bao et al. [81] and Armstrong et al. [60] suggest that the HAL TLV action limit could be lowered.

In addition to their external validity, that is, how well they are predictive of disease or morbidity, a consideration in the application of observational-based methods is their *internal validity*. Internal validity refers to how well the methods represent the exposure variable(s) they are intended to quantify. Methods for characterizing exposure based on visual observation and estimation of risk factors should be interpreted with an appreciation for the limitations in the ability of observers to make accurate estimates of the risk factor levels. This has been illustrated most clearly for the visual estimation of working posture. In general, the posture category boundaries of job analysis methods have not been selected based on empirical studies of what job analysts can reliably detect by visual observation.

Studies of the accuracy of posture estimation from video recording suggest that postural misclassification errors are inversely proportional to the size of the joint segments of interest [74,82]. When considering the width of angular posture categories (in degrees), a trade-off exists between the probability of error occurrence and the magnitude of the error when one is made [82,83]. van Wyk et al. [83] recently illustrated this concept empirically by deriving posture categories that optimize the probability of occurrence of misclassification errors and the magnitude of the errors as a function of the posture category width. The example shown in Figure 32.6 represents elbow flexion/extension and indicates an optimal category width of 25–30 degrees. Since elbow flexion/extension has approximately 120 degrees in the functional range of motion, van Wyk et al. [83] suggest that a four category scale in 30° increments is optimal in consideration of the accuracy of observer judgment. Table 32.5 shows the posture categories that optimize visual

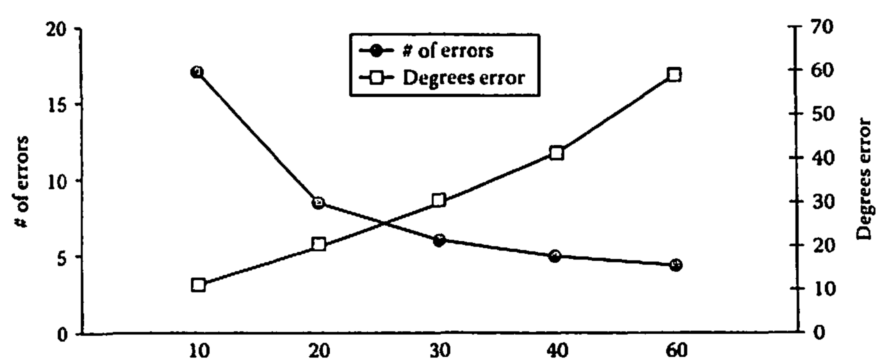


FIGURE 32.6 Optimized posture category size for elbow/flexion extension showing the trade-off between the probability of posture misclassification (number of errors made) and the misclassification error magnitude (in degrees). (Reproduced from van Wyk, P.M. et al., *Ergonomics*, 52, 921, 2009. With permission.)

TABLE 32.5 Optimal Posture Category Widths (in Degrees) and Number of Categories for Trunk, Shoulder, and Elbow Postures

	Trunk Flexion	Trunk Lateral Bend	Shoulder Flexion	Shoulder Ab-/Adduction	Elbow Flexion
Category width	30°	15°	30°	30°	30°
Optimal number of categories	4	3	5	5	4

Source: From van Wyk, P.M. et al., *Ergonomics*, 52, 921, 2009.

judgment of posture based on the van Wyk et al. [83] study. While this represents only a single study and did not include wrist postures, these findings are in line with those of Bao et al. [81] who concluded that interrater reliability was superior with 30° posture category widths versus a smaller width, and that for most postures, 30° angle intervals appear to be appropriate. It should be noted that for radial/ulnar deviation of the wrist, an interval of 30° from neutral represents most, if not all, of the effective range of motion. Thus, wrist radial/ulnar deviation presents a dilemma in designing posture scales with categories that are small enough to capture differences in biomechanical risk, yet large enough that the angular intervals can be visually discriminated by observers conducting the posture analysis. Because of the relatively small size of the body segments, and smaller range of movement, visual discrimination of wrist radial/ulnar deviation is problematic for observational posture assessment [82,84].

32.6.2.4 Example of Observational-Based Exposure Assessment

An example of the application of the HAL TLV is as follows. A job on an automotive radiator assembly production line was video recorded, and the hand force profile for the dominant (right) hand was determined using two approaches. The first approach was with a wearable glove with thin profile force sensors attached to the palm surface to measure hand contact force with the dominant hand. Figure 32.7 (top panel) shows a force profile for a typical work cycle with a cycle time of 15 s. The second approach was using the Multimedia Video Task Analysis, or MVTA, system (see Section 32.6.4) and manually marking video frames at the transition points between hand force and no hand force exertion. Using MVTA, five periods of hand force exertion were identified for the right hand (see Figure 32.7, middle panel). These correspond closely to five distinct exertions of force evident from the direct-reading measurement (top panel). The total time duration of the force exertions sums to 7.6 s, resulting in a duty cycle of 50%. A 15 s work cycle with five exertions yields a force frequency of 0.33 exertions per second. Using Table 32.4, the HAL rating was obtained for this combination of exertion frequency and hand force duty cycle, and was determined to be greater than 3 and less than 4. Thus, a range of 3–4 was used. The normalized peak hand force in the grip of the radiator when lifting it from the pallet was estimated to be between 40% and 50% of MVC. By plotting the HAL and normalized peak force as shown in Figure 32.7 (bottom panel), it can be determined that the job falls above the action limit (dashed line) but below the TLV and can be characterized as a job in which some form of intervention should be considered.

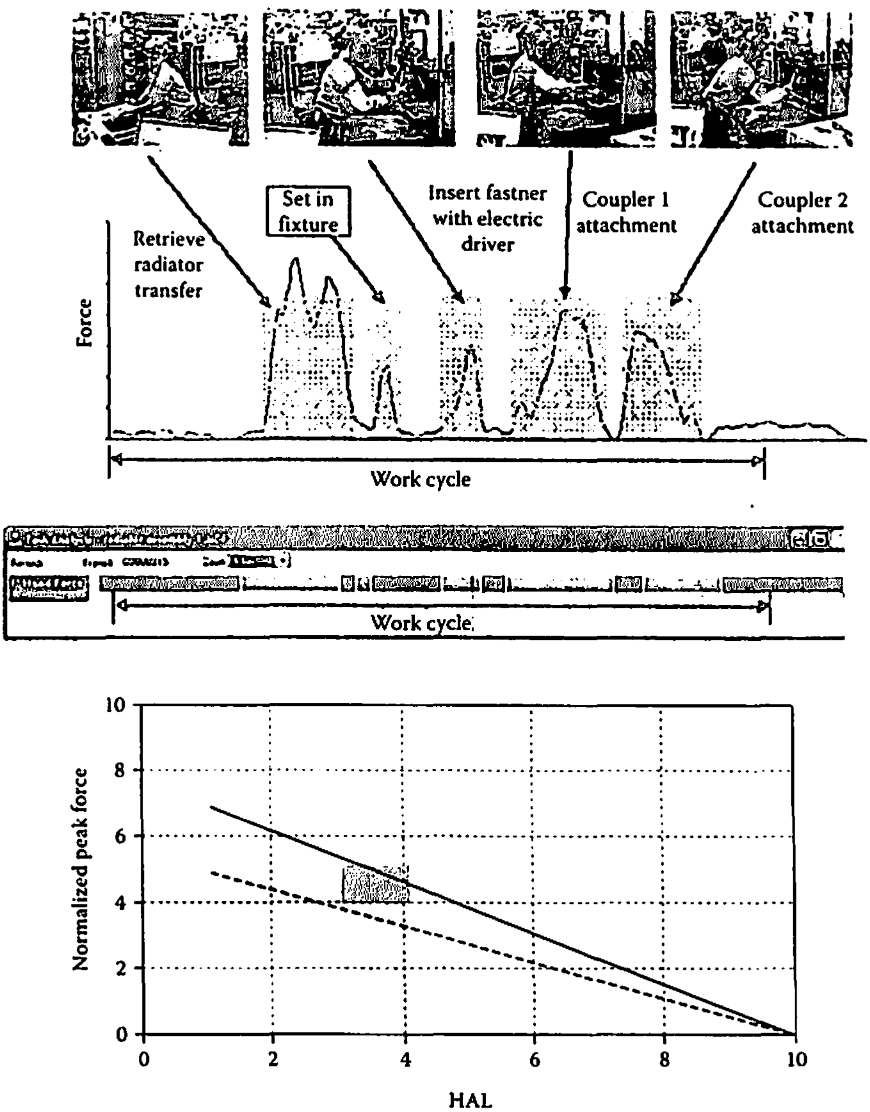


FIGURE 32.7 Example of HAL calculation (top and middle panels) and interpretation (bottom panel). The top panel shows a continuous recording of hand force and the middle panel an observational analysis of exertion duty cycle using the MVTA™ software.

32.6.3 Continuous-Recording Instrumentation-Based Methods

Though not the most widely adopted, it is generally believed that the most valid approach to quantifying physical risk factors for upper limb CTDs is by direct measurement with continuous-recording instrumentation [47,56]. UECTD risk factors have been quantified with a variety of continuous-recording measurement instrumentation, most notably those for measuring muscle electrical activity (electromyography), external muscle force (load cell/strain gauge transducers, thin profile pressure and force sensors), joint motion, or kinematics (electrogoniometry), limb segment orientation (inclinometry), and vibration (accelerometry). Motion capture systems, which are based on optical and magnetic technologies, have been used in studies conducted in more controlled environments, but are generally impractical in industrial settings.

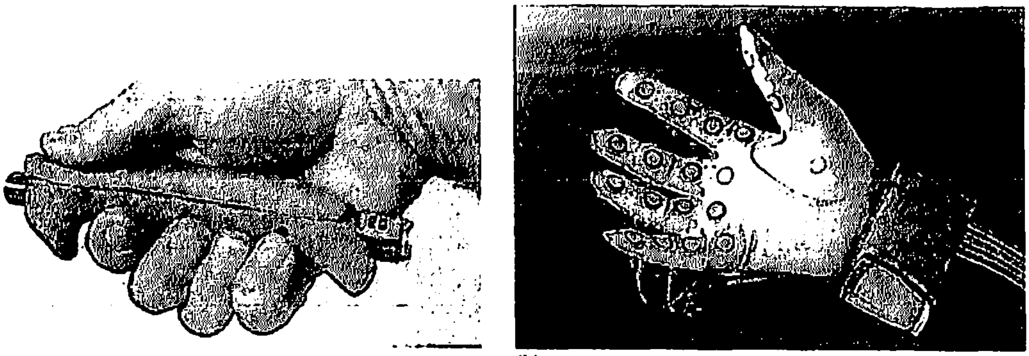
The following is a brief overview of continuous-recording instrumentation applicable in the assessment of UECTD risk factors.

32.6.3.1 Force Exertion

The surface electromyogram (SEMG) is a recording of the electrical activity in underlying skeletal muscle detected by electrodes attached to the skin surface over the belly of the muscle. SEMG recordings are typically subjected to data reduction and analysis of amplitude as a correlate of force exertion or amplitude and/or frequency spectra as indicators of muscle fatigue [85,86]. The amplitude of the detected electromyogram (EMG) signal is referenced (or normalized) to a known level of muscle contraction in a standardized exertion, and subsequent amplitudes can be expressed as percentages of the reference exertion force output. The reference exertion can be elicited as the maximum force the worker can exert (the *maximum voluntary contraction*, or MVC) or a submaximal exertion level that is controlled by standardizing a static load on the muscle. As an example, power grip force on a grip dynamometer can be calibrated (or normalized) to the SEMG amplitude of extrinsic muscles in the forearm that create forceful flexion of the fingers in the grip [87]. This SEMG to force relationship can be used to convert the SEMG measured in a gripping task to an equivalent dynamometer grip force level, provided that grip span and wrist posture are equivalent.

Normalized SEMG has also been interpreted with respect to the duration of intensity levels and their frequency of occurrence as a percentage of working time. This approach has been labeled exposure variation analysis [86,88] and has been applied to examine activity in non-cyclic work where force exertions vary and lack fundamental work cycles [89]. A simpler approach is to express the SEMG activity in terms of its amplitude probability distribution function (APDF), where the cumulative frequency or probability of occurrence is plotted against exertion level [90].

Some investigators have adopted or developed specialized systems for the continuous time measurement of external force exertion by the hand, which are particularly applicable to the grip force on tool handles. Two examples of such systems require either fabrication of special handles with embedded force transducers [91] or the application of thin flexible pressure sensors between the surface of the handle and the hand [92–94]. As an example of the former, Liberty Mutual has developed a Hand Tool Force Measurement System [91] based on an instrumented handle core with embedded strain gauges. The system has been used to measure multi-axis compression forces in the grip of the handle and moments at the cutting blade of a knife used in a variety of poultry processing jobs (see Figure 32.8a). As an example of the latter, Kong and Lowe [94] instrumented a wearable glove with thin profile force sensors on the phalangeal segments and metacarpal heads of the palm surface to measure finger segment contact force in the power grip of tool handles (see Figure 32.8b). A wearable force sensor system has the advantage of versatility, in that measurement of hand contact force is not limited to the particular tool that is instrumented. This contrasts with the embedded strain gauge approach where sophisticated fabrication of a single tool



(a) (b)

FIGURE 32.8 (a) Knife handle instrumented for grip forces in three axes and moments with force transducers embedded in the cylindrical core. (Photo courtesy of R. McGorry, Liberty Mutual Research Institute for Safety.) (b) Wearable (glove-attached) thin profile resistive sensors for measurement of contact force on the phalangeal segments and metacarpal heads.

handle can be costly and time-consuming. However, a disadvantage of the wearable thin profile sensor approach is that the measurement depends on the completeness of sensor coverage on the palm surface in contact with the object in the grip. The wearable glove approach is also intrusive, as the measurement device itself may alter the subject's interaction with the handle. Force transducers embedded in a tool handle accurately resolve the resultant forces on the handle unintrusively and are independent of the distribution of contact surface on the handle.

32.6.3.2 Posture and Motion

The most commonly reported instrumentation-based measurements of posture and motion of the hand, wrist, and forearm have been acquired using electrogoniometry. An electrogoniometer is a device that measures joint displacement using a transducer that spans the joint of interest. Wrist electrogoniometers commonly have an endblock attached on the metacarpal bones of the hand and on the forearm proximal to the wrist. The flexion/extension and radial/ulnar deviations of the wrist can be detected by these transducers (refer to Figure 32.4). Rotation of the forearm (supination/pronation) requires a torsional sensor in which twist between the device endblocks are calibrated to a degree of axial rotation.

An applied example of the use of electrogoniometry to quantify wrist and forearm motions is the study of Albers and Hudock [95]. This study evaluated risk factors associated with hand rebar tying with a traditional method using manual pliers and with a handheld battery-powered automated tying device. Electrogoniometry was used to quantify the reduction in wrist/forearm motions associated with the automated device relative to the hand-tying method. Ironworkers tied rebar intersection points at ground level in the grid of rebar that provided reinforcement to a poured concrete bridge surface (see Figure 32.9). The rebar segments intersected at 7 in. intervals, and 75% of the total intersection points required tying. Electrogoniometric recordings were made for approximately 30 min for each of three tying devices: the conventional manual method with pliers, an automated battery powered tying device, and the battery-powered device with an extension handle

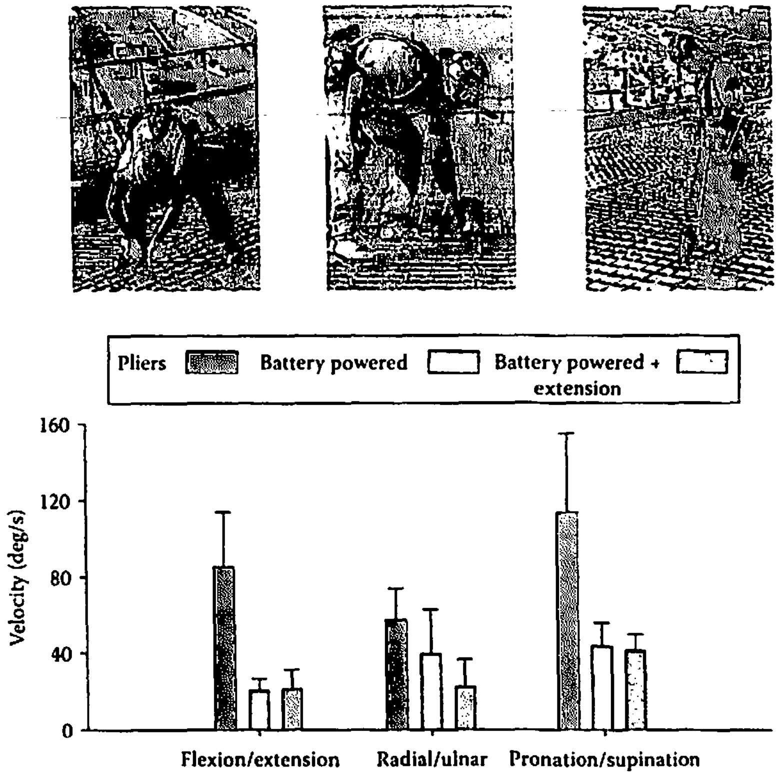


FIGURE 32.9 Example of electrogoniometry used to measure mean (+s.d.) wrist motion velocities for three methods of rebar tying: manual pliers tying, battery-powered tying, and battery-powered tying with the addition of an extension handle. The bar graph shows the substantial reduction in wrist motion velocities, particularly for flexion/extension and pronation/supination, with the battery-powered tying device. (From Albers, J.T. and Hudock, S.D., *Int. J. Occup. Saf. Ergon.*, 13, 279, 2007. With permission; photos by Earl Dotter.)

designed to reduce or eliminate trunk bending (see Figure 32.9). This was an ideal application for wrist electogoniometry since the traditional approach of hand tying rebar with pliers is associated with many repetitive high-velocity wrist and forearm motions that could not be reliably estimated by visual judgment. Albers and Hudock [95] reported that wrist motion velocities in the flexion/extension, radial/ulnar deviation, and forearm rotation (supination/ pronation) axes were reduced by 76%, 30%, and 63% respectively by adoption of the automatic rebar tying device. (Figure 32.9).

Inclinometry is a method for dynamically assessing the orientation of a limb segment with respect to gravity. One example is when the inclinometer is attached to the upper arm segment, the device can be calibrated to arm orientation and used to evaluate upper arm elevation [76].

32.6.3.3 Direct-Reading Exposure Assessment Methods (DREAM)

While direct-reading instrumentation is believed to be the most objective and quantitative method for assessing risk factor exposure, its use in occupational ergonomics appears to be highly concentrated in research applications. In a survey of Certified Professional

Ergonomist (CPE) practitioners, Dempsey et al. [96] found that 31% of CPEs reported having ever used EMG and, of these, only 2% rated EMG as "easy to use." Conversely, 52% of practitioners reported having used RULA, and 20% of these rated RULA as easy to use. A similarly low rating for *easy to use* was reported for electrogoniometry, which only 18.5% of CPEs reported as having ever used. A trend within these data appears to be that direct-reading measurement techniques are not viewed as favorably, or are not as widely adopted, by practitioners for assessing risk factor exposure in ergonomic analyses.

Advances in sensor technologies and portable direct-reading instruments for other physical agents such as noise, radiation, aerosols, and dust have led to an initiative in 2008 by NIOSH in the area of *Direct-Reading Methods* [97]. Under this initiative, the vision for direct-reading methods (DRMs) in occupational exposure assessment is based on a self-contained instrument, wearable by the worker that can "...provide on-site measurement of exposures in units (such as parts per million parts of air, or ppm) that indicate whether or not the exposures pose an occupational health or safety risk and if the prevention methods employed are actually providing the proper level of protection" [97]. This definition is clearly inspired by the monitoring of air-borne chemical agents and the sampling of hazards to which workers are exposed through respiratory or dermal pathways. Nonetheless, this initiative may benefit the area of MSD prevention and CTD risk assessment if novel and improved technologies for measuring the risk factors of force, posture, repetitive motion, and vibration result.

NIOSH and the American Industrial Hygiene Association sponsored a workshop in 2008 to address research needs related to DRMs for occupational exposures to hazards related to noise, radiation, aerosols, surface sampling and biomonitoring, gases and vapors, and ergonomics. The workshop titled "Direct-Reading Exposure Assessment Methods" (D.R.E.A.M.) served to solicit stakeholder input for the purpose of developing a research agenda for DRMs for exposure assessment. The ergonomics and vibration breakout session of the workshop focused on DRMs for the hazard of physical loading on the musculoskeletal system and the assessment of exposure to biomechanical risk factors for WMSDs. Discussion centered on the importance of immediate interpretation of exposure data, that is, to provide a real-time indication of exposure level. Real-time acquisition of data in the workplace (on-site) is necessary. However, the group was somewhat divided on the need for real-time *interpretation* of the data. Some participants felt that there was a need for DRMs to acquire the exposure data and interpret the measured exposure level in real-time. An example of such a scenario is when immediate feedback to the worker is desirable for changing work habits or technique, or as a form of biofeedback. Other participants believed that the real-time interpretation of exposure is not a necessary characteristic for a DRM and that post-processing of the data may be necessary for reconstruction and interpretation of exposure level. It was generally agreed that reducing data post-processing time is desirable. The discussion also emphasized the need to improve the usability, portability, and ruggedness of existing technologies or in the development of new technologies.

32.6.4 Computer Video-Based Task Analysis and Video Exposure Monitoring

Observational-based ergonomic assessments have traditionally been conducted by pencil and paper documentation of risk factors observed with the aid of analog video playback equipment. Some approaches to posture analysis have integrated computerized exposure documentation with observation from analog video tape recording [98]; however, prior to the digital video camcorder, these methods were less common. Advances in digital video recording technology have greatly simplified the integration of video playback and computer-assisted exposure assessment and time study. Digital video and computer-based time study and task analysis systems are now commonly used to aid the process of ergonomic job analysis. Commercial systems are available that provide a user interface to control the playback of digital video and facilitate manual event marking that allows an analyst to delineate exposure or task analysis events on a graphical time line. The software will calculate descriptive summary statistics for risk factor durations and category transitions. Summaries can include data such as the percentage of the work cycle with postures in non-neutral posture categories [99], or counts, durations, and frequency of hand force exertion [100].

One example of such a computer-based method is the MVTA™ [101,102]. MVTA has been used by several investigators to quantify upper limb risk factor levels in detailed observational-based exposure assessment. As an example, Bao et al. [81] described the continuous observation time-based posture analysis as one in which a posture is observed continuously and transitions between angular categories are documented on the timeline. Subsequent processing and analysis results in a distribution of posture among the categories. The advantages of a computerized system to control video playback and perform all of the timekeeping functions for this type of observation and recording of posture are obvious. As a result, computer-based systems such as MVTA are solidifying their place in a number of epidemiologic studies and ergonomic analyses of UECTD risk factors in which more complete exposure profiles are needed.

Video exposure monitoring (VEM) is related to computer video-based task analysis and time study. VEM can be broadly defined as the approach whereby a worker's specific activities can be visualized synchronously with quantitative data on exposure levels or exposure transitions [103–105]. In VEM, the video recording is made synchronously with continuous time exposure sampling, and the exposure level is overlayed graphically on the video image [103]. This was originally accomplished with analog video tape and a variable graphics array (VGA) card or adapter; however, a similar integrated system can now be accomplished with computer software and a digital video camera.

An example of a VEM system for visualizing the exertion of hand grip contact force is shown in Figure 32.10. This system was developed on the LabVIEW (National Instruments, Austin, TX) software platform and synchronized data acquisition from thin profile force sensors attached to the palmar surface of the hand with video capture from a consumer video camcorder [106]. Digital video frame grabbing was accomplished through an IEEE bus interface and a custom LabVIEW program which incorporates the Vision Development Module toolkit. In each iteration of the execution loop, a single video frame is grabbed with a sample from 20 force sensors. The frame grab images are appended in sequence to create a video file (.avi file format) in which each frame is synchronized with a force sample. A playback interface allows the viewer to scrub across the force time series trace while the corresponding video frame display is updated.

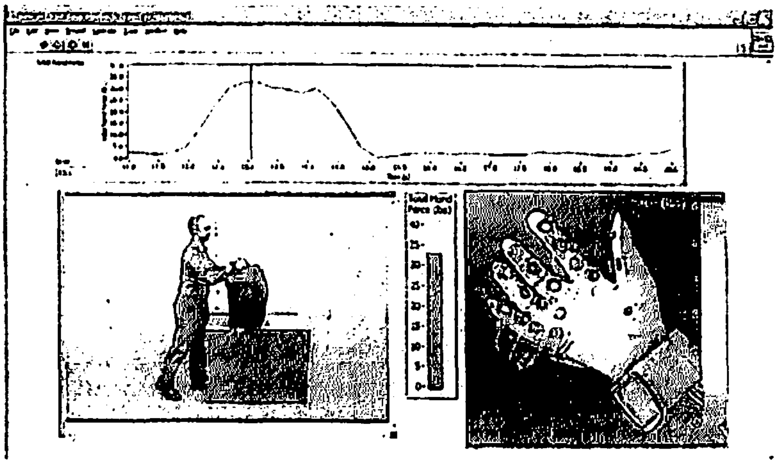


FIGURE 32.10 A VEM system that synchronizes video recording with direct measurement of hand contact force. The playback mode allows for scrolling the cursor across the total hand contact force time series trace (top) to continuously update the corresponding video frame (lower left) and the spatial force distribution representation on the hand (lower right).

32.7 REGULATORY ACTIVITY: OSHA AND NIOSH

32.7.1 Regulatory Activity and OSHA

The period of 1995–2000 resulted in a successful effort on the part of the OSHA in drafting and passing an Ergonomics Rule to address MSDs in general industry. In November 1999, OSHA issued a draft standard and the agency made significant changes from the original proposal, after listening to more than 700 witnesses during a nine-week public hearing and reviewing more than 8,000 public comments on the proposal. The final ergonomics program standard appeared in the November 14, 2000 edition of the Federal Register and took effect January 16, 2001. The rule had the following requirements:

Management leadership and employee participation: The employer was required to set up an MSD reporting and response system and an ergonomics program and provide supervisors with the responsibility and resources to run the program. The employer was also required to assure that policies encouraged, and did not discourage, employee participation in the program or the reporting of MSD signs, symptoms, and hazards. Employers were required to give employees the opportunity to participate in the development, implementation, and evaluation of the ergonomics program.

Job hazard analysis and control: If a job met an Action Trigger, the employer was required to conduct a job hazard analysis to determine whether MSD hazards existed in the job. If hazards were found, the employer was required to implement control measures directed at reducing hazards to the extent "feasible."

Training: The employer was required to provide training to employees in jobs that met the Action Trigger, their supervisors or team leaders and other employees involved in setting up and managing the ergonomics program. Training should include the hazards present in the problem job, and the signs and symptoms of the disorders that could result, while also encouraging early reporting of MSDs.

MSD management: Employees were to be provided, at no cost, with prompt access to a health care professional (HCP), evaluation and follow-up of an MSD incident, and any temporary work restrictions that the employer or the health care provider determined to be necessary.

Work Restriction Protection: Employers were required to provide work restriction protection (WRP) to employees who received temporary work restrictions. This meant maintaining 100% of earnings and full benefits for employees who receive limitations on the work activities in their current job or transfer to a temporary alternative duty job and 90% of earnings and full benefits to employees who were removed from work. WRP was to be good for 90 days, until the employee was able to safely return to the job, or until an HCP determined that the employee was too disabled to ever return to the job, whichever came first.

Program evaluation: The employer was required to evaluate their ergonomics program every three years to make sure it is effective.

Record keeping: Employers with 11 or more employees, including part-time employees, were required to keep written or electronic records of employee reports of MSDs, MSD signs and symptoms and MSD hazards, responses to such reports, job hazard analyses, hazard control measures, ergonomics program evaluations, and records of work restrictions and the HCP's written opinions.

The OSHA ergonomics rule was short-lived. In March of 2001, under a new administration, the ergonomics rule became the first and, to this date, the only federal regulation to be repealed under the Congressional Review Act, a 1996 bill that gives Congress the power to overturn federal regulations. This bill provided a mechanism for Congressional review and repeal of legislation, and even enables the retroactive repeal of existing legislation within a specific time frame, as was done in this case.

Following the 2001 repeal of the ergonomics rule, OSHA's emphasis shifted to a four-pronged approach which included the development of voluntary ergonomics *guidelines, enforcement efforts under the General Duty Clause, outreach and assistance efforts, and the formation of a National Advisory Committee on Ergonomics*. The emphasis on voluntary guidelines has resulted in the publication of industry-specific guidelines for nursing homes (2003), poultry processing (2004), retail grocery stores (2004), and shipyards (2008).

The repeal of the ergonomics rule in 2001 has not negated OSHAs ability to levy citations to employers with ergonomic hazards in their facilities. In the absence of an industry standard to address ergonomic hazards, OSHA had used, and can continue to use, Section 5(a) (1) of the Occupational Safety and Health Act as the authority to cite. Known as the General Duty Clause, Section 5(a) (1) states that "*...each employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees.*" Opponents of the ergonomics rule had claimed that such a specific ergonomics regulation was unnecessary because the General Duty Clause was a mechanism by which OSHA could regulate for ergonomic hazards. However, since the repeal of the proposed rule in 2001, the number of citations for ergonomic-related hazards has seen a marked decrease. In 2009, OSHA's Directorate of Enforcement Programs indicated that the agency has issued 19 General Duty Clause citations for ergonomics since 2002. During the same time period, OSHA conducted 4500 ergonomic inspections and issued 640 hazard alert letters on ergonomics. In comparison, during the 10 year period between 1985 and the 1995 first edition of this text, OSHA had issued over 350 citations for either lifting or UECTD hazards.

Outreach and assistance efforts have placed emphasis on voluntary protection and a Voluntary Protection Program (VPP) based on incentivizing best practices to meet safety and health goals. However, concerns exist regarding the effectiveness of non-regulatory approaches to incentivizing occupational safety and health efforts, and such concerns may be well founded. Recently, the Government Accountability Office [107] identified OSHA VPP participants with high injury and illness rates—higher in fact than their industry averages. One employer had an injury and illness rate four times higher than the average rate for its industry. In response to this report, OSHA committed to conduct comprehensive evaluation of the VPP. VPP employers are supposed to have exemplary safety records. While participating industries remain subject to OSHA inspections following fatalities, serious injuries, or workers' complaints about safety or health hazards, they have been exempted from routine inspections. OSHA Alliance programs make up another component of outreach and assistance. These Alliances serve to help industry organizations build trusting, cooperative relationships with OSHA, network with others committed to workplace safety and health, leverage resources to maximize worker safety and health protection, and gain recognition as proactive leaders in safety and health. OSHA currently maintains Alliance Programs with 11 industry organizations (examples include the American Dental Association, American Society of Safety Engineers, Association of Occupational Health Professionals, Association of PeriOperative Registered Nurses, and the Brick Industry Association, among others). These Alliances have led to numerous industry-specific training tools and products.

The *National Advisory Committee on Ergonomics* was chartered in 2003–2004 and made several recommendations to OSHA for its MSD program. In addition to prioritizing the top 16 industries for which ergonomics guidelines should be developed, NACE advised OSHA to consider the following research gaps:

- More research is needed to examine the validity of techniques used to establish a diagnosis of MSDs.
- More research is needed to examine the role of psychosocial factors that contribute to or impact the development of MSDs.
- More studies are needed to develop additional animal models in which the effects of physical loading on living tissues can be studied in a controlled manner.

- More studies are needed to examine the validity and reliability of existing exposure assessment methods.
- More studies are needed to determine the economic impact to organizations of what are commonly described as ergonomic interventions.
- More studies are needed to address the multifactorial causes of MSDs, such as psychosocial, physical, occupational, and non-occupational factors, and their interactions.
- Additional studies are needed to describe the natural history of diseases or injuries, commonly known as MSDs.
- More studies are needed regarding factors in workers' compensation systems and other statutory payment mechanisms on findings of causation, diagnosis, duration of the disability, and other outcomes related to what are commonly known as MSDs.

Two states (California and Washington) have passed ergonomic standards enforceable at the state level. California's standard went into effect in July 1997 and requires that "...every employer subject to this section shall establish and implement a program designed to minimize repetitive motion injuries (RMIs). The program shall include a worksite evaluation, control of exposures which have caused RMIs and training of employees." California's rule applies to a job, process, or operation where an RMI has occurred to two or more employees. Washington state adopted an ergonomics standard in May 2000, with a phased-in enforcement that was scheduled to begin in July 2004. The Washington state standard required employers with "caution zone jobs" to find and fix ergonomic hazards instead of waiting for an injury to occur before taking action. On July 12, 2002, a county court rejected a business coalition's contention that the state exceeded its authority under state law, acted arbitrarily, and did not follow its rule-making requirements. During the process of appeal to the state supreme court, Washington state voters passed an initiative in the November 2003 election to repeal the state's ergonomics standard. Thus, California currently maintains the only ergonomics standard at the state level.

32.7.2 National Occupational Research Agenda

The National Occupational Research Agenda (NORA) was unveiled by the NIOSH in 1996 to provide a framework for research collaborations among universities, large and small businesses, professional societies, government agencies, and worker organizations. The NORA team charged with developing a research agenda for workplace MSDs published a report in 2001 [108] documenting the most important research priorities. These priorities included surveillance research, etiologic and medical research, intervention research, and efforts to improve the research process by strengthening communication between researchers and practitioners who apply research.

The agenda for improving surveillance research included such objectives as developing user-friendly, standardized workplace surveillance tools; increasing collaboration with federal, state, and non-governmental organizations to encourage comparability of data collection methods; and conducting an ongoing national hazard survey targeting physical workplace factors.

The research agenda for improving etiologic and medical research included the following:

- Refine instruments to detect and quantify the contribution of excessive force, awkward posture, movement, and vibration to the disease process.
- More clearly define stages of the MSD process, develop precise diagnostic tools, and provide guidelines for effective treatment and return to work.
- Clarify the interplay of the factors at different stages of causation, development, and treatment of MSD and measurement of risk factors.

Priorities for intervention research included evaluating the effects of the following on the development and prevention of MSDs:

- Alternative (product and/or tool) design criteria (force, spatial requirements of work)
- Optimization of mechanical work demands, such as force, movement, and posture, and temporal patterns of exposure
- Manual handling alternatives in posture, movement, force, productivity, and quality
- Ergonomic training and education
- Costs and benefits of ergonomic intervention
- Evaluate job assignment, selection, and choice on development of MSD
- Emerging technologies

Now in its second decade, NORA emphasizes meeting the occupational safety and health needs of the eight industry sectors, which are broken out according to the North American Industry Classification System (NAICS) code. Eight sector programs have been established to develop specific agendas that address the occupational safety and health needs of stakeholders in each industry sector. Strategic goals aimed at reducing the prevalence of MSDs for the low back and upper extremities are evident in all sectors. Upper limb CTDs have been identified as a high priority across all industry sectors.

32.8 FUTURE CONCERNS

If recent history is a good predictor, the regulatory landscape with respect to ergonomics and MSDs will continue to be shaped largely by political and economic factors. These factors are difficult to project beyond the short term, and it is difficult to predict the likelihood, much less the scope, of future regulatory activity affecting workplace prevention of UECTDs. However, there are clear trends in the U.S. workforce and labor market that can be anticipated to impact the way ergonomics professionals approach their discipline. The first, and most quantifiable, trend is the aging U.S. workforce. During the period 2006–2016, the number of workers aged 55–64 is expected to increase by 36.5%, and the number of workers over age 65 will increase by more than 80%. This will continue the current trend in which older workers make up a progressively larger percentage of the labor force. A second trend is the diversification of the workforce. Among those over 65 years of age, the percentage growth of women in the workforce greatly exceeds that of men. These changes in the demographics of the labor force underscore the need to consider the physical capabilities, such as strength, range of motion, dexterity, anthropometry, and metabolic work capacity of the specific worker population of interest.

No less significant of a future concern is the changing nature of work in U.S. industry. The way that work is organized affects exposures to physical and psychosocial risk factors for UECTDs. Automation and enhancements in process efficiency may result in a reduction of the highest biomechanical loads on the worker imposed by the gross handling of materials, but the positive effects of such automation may be negated by a resulting increased pace of work. It has been suggested that workplace exposures are shifting to less forceful but more frequent motions [109] performed in less-conventional environments. With increases in the service sector and warehousing distribution-related industries, fewer workers as a percentage of the labor force are employed in jobs organized around the traditional manufacturing assembly line. Physical exposures may be more difficult to assess in jobs with the characteristics observed in these sectors.

Evidence suggests that the changing nature of work has served to increase psychosocial stressors in the workplace. These stressors continue to be on the rise, driven by trends toward globalization, outsourcing, "right-sizing," longer work hours, and decreased job security for many workers. A growing body of evidence implicates psychosocial stresses in the etiology of UECTDs.

Trends toward non-traditional and flexible employment practices have raised concerns about the effect of such practices on worker safety and health. According to data from the BLS Current Population Survey, agency-supplied temporary workers and workers in other alternative employment arrangements (independent contractors, contractor-supplied labor, day laborers, and on-call workers) accounted for nearly 10% of the workforce in 2001 and represent a growing percentage of the labor force. The Current Employment Statistics Survey (CES) showed, for example, that the total number of jobs in the temporary help industry multiplied sixfold (to nearly 3 million) during the period 1982–1998, whereas total employment during this period grew by only 40%. It has been suggested that flexible employment practices are leading to a downward restructuring of the labor market with the temporary labor force becoming the group exposed to the most severe workplace hazards and health risks. This group of workers is the least trained to recognize and report ergonomic workplace hazards and CTD risk factors, the least protected by benefits and traditional employer obligations under labor law, and the most difficult for which to track physical exposure and prevalence of UECTDs. This may increase the difficulty of accurately representing the scope of UECTD problems in the workplace.

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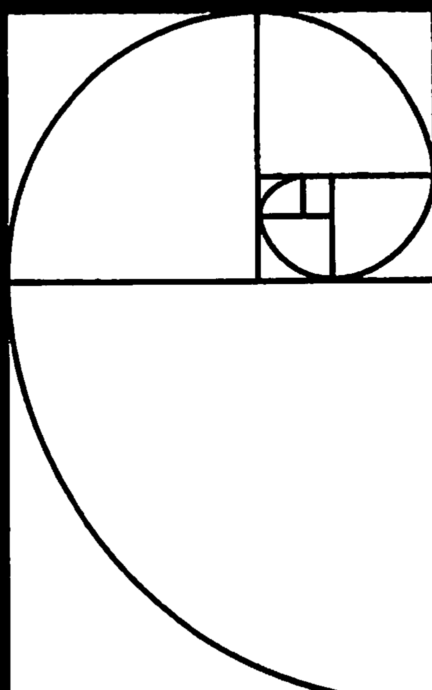

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