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UPPER-EXTREMITY MUSCULOSKELETAL DISORDERS OF OCCUPATIONAL ORIGIN

Fredric Gerr, Richard Letz, and Philip J. Landrigan

Division of Occupational and Environmental Medicine, Department of Community Medicine, The Mount Sinai School of Medicine, New York, NY 10029

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INTRODUCTION

A large literature, relating upper-extremity musculoskeletal disorders to occupational factors, has evolved over the past 100 years. Such disorders have been considered endemic in certain industries, such as meat processing and packing. They also have been reported to occur with high frequency in other trades, such as construction, clerical work, forestry, product fabrication, garment production, health care, underground mining, and the arts (15, 20, 28, 31, 39, 68, 73, 75, 82). In the Bureau of Labor Statistics category "disorders associated with repeated trauma," upper-extremity musculoskeletal disorders are included, for reporting purposes, with other conditions associated with repeated motion, pressure, or vibration, such as noise-induced hearing loss. For this reason, precise estimates of the prevalence of these disorders are not available. It is nevertheless suggestive that, in 1988, the most recent year for which statistics are available, disorders associated with repeated trauma accounted for 48% of all reported occupational diseases (87), a substantial increase from 18% reported in 1982. Upper-extremity musculoskeletal disorders account for the majority of these reports (63).

Occupational epidemiologic studies of upper-extremity musculoskeletal disorders, including tendinitis and carpal tunnel syndrome (CTS), have variously reported etiologic associations with repetitive motion, hand force, awk-

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ward posture, insufficient frequency of rest breaks, exposure to vibration, and job content or "psychosocial" factors. However, much of the literature examining the relations of upper-extremity musculoskeletal health outcomes to these occupational factors has been flawed. Few studies have employed either rigorous assessments of exposure or well-defined objective measures of outcomes. Consequently, the work-relatedness of many upper-extremity disorders remains controversial.

In this review we shall critically evaluate the scientific evidence that relates occupational factors to musculoskeletal disorders of the upper extremities. Specifically, we shall (*a*) discuss methodological issues, (*b*) define the terminology used in this field and address ambiguities, (*c*) discuss the problems of diagnosis and etiologic attribution that are posed by poorly defined clinical entities characterized by pain and occupational disability, (*d*) review the literature relating musculoskeletal disorders to use of video display terminals (VDTs), (*e*) draw conclusions regarding the work-relatedness of these disorders, and (*f*) present recommendations for further research.

BACKGROUND

The 1971 United States Health Interview Survey estimated that over 18 million noninstitutionalized adults, aged 25–74, suffered from musculoskeletal impairment, and that 2,440,000 of those cases involved the upper extremity or shoulder (22, 45). In 1981, the direct economic cost associated with upper-extremity disorders in the United States was estimated to be over $22 billion (52). Although many of the musculoskeletal disorders identified in large surveys of Americans were due to nonoccupational factors, occupationally related disorders, especially those affecting the upper extremities, are becoming recognized as significant contributors to the overall prevalence of musculoskeletal disease.

The relationship between work and painful musculoskeletal disorders was first described by Ramazzini over 200 years ago:

> ". . . certain violent and irregular motions and unnatural postures of the body, by reason of which the natural structure of the vital machine is so impaired that serious diseases gradually develop therefrom." (70, p. 15)

The National Institute for Occupational Safety and Health (NIOSH) recently has designated occupationally related musculoskeletal disorders as one of the five leading categories of occupational diseases and injuries (15).

Widespread "outbreaks" of upper-extremity musculoskeletal pain have been reported in Japan and Australia over the past two decades. As many as 28% of workers in some departments of a large Australian telecommunications company were affected over a five year period (42). Anecdotal reports suggest the existence of similar problems in certain industries in the United States. For example, a recent NIOSH Health Hazard Evaluation at a large daily newspaper in the northeast United States found that 40% of the participating employees reported having experienced "symptoms compatible with upper-extremity cumulative trauma disorders" during the year preceding the evaluation (61).

Interest in these disorders has emerged recently in the lay press. Record fines levied by the United States Occupational Safety and Health Administration for violations of health and safety regulations intended to prevent occupational musculoskeletal disorders have been major news stories (2, 41), as have special features, such as the *New York Newsday* story "Repetitive Strain Injury May Be Occupational Disease of the '90s" (72).

The peer-reviewed medical literature is rich with studies that attempt to relate occupational factors to musculoskeletal disorders. The affected tissues include the tendons, tendon sheaths, muscles, nerves, bursae, and blood vessels (64). Musculoskeletal disorders that are commonly described in the literature as related or potentially related to occupational factors are listed in Table 1.

Table 1 Musculoskeletal disorders and associated occupational factors reported in the literature

Upper-Extremity Disorder	Occupational Factors
Carpal tunnel syndrome	force [14, 16, 59, 78, 85] repetition [8, 14, 16, 29, 78] awkward posture [16, 27, 55, 56, 86] vibration [16, 29] mechanical stress [86]
Tendinitis	force [5, 53, 91] repetition [5, 51, 53, 71, 91] awkward posture [53, 91] insufficient rest [69]
Epicondylitis	unaccustomed forceful movement [49] repetition [49] forceful grip [79] repeated supination/pronation [79, 88]
Shoulder/neck disorders	overhead work [1] static muscle load [38, 39, 89]
Hand-arm vibration syndrome	segmental vibration [10, 18, 19, 33, 40, 60]
Arm pain in office workers	use of video display terminals [47, 61, 73, 80, 82] psychosocial or workplace organizational factors [72, 82, 87]

Authors of recent reviews (7, 17, 29, 39, 57, 64, 84) have attempted to evaluate and summarize the literature regarding these disorders. These reviews reflect a growing consensus that occupational factors can place workers at increased risk for the development of upper-extremity musculoskeletal disorders. Authors repeatedly note, however, that much of the epidemiologic evidence for the work-relatedness of these disorders is of poor quality. The evidence often consists of little more than case series of affected industrial workers. Few studies have been reported in which rigorous assessment has been made either of exposure or of well-defined health outcomes. This relative lack of sound epidemiologic evidence has led some authors to question the validity of the notion that occupational factors can cause musculoskeletal disorders of the upper extremities (37).

REVIEW OF TERMINOLOGY

The nomenclature describing upper-extremity musculoskeletal disorders of occupational origin is confusing and internally inconsistent. Some terms refer to well-defined clinical entities (i.e. CTS, tendinitis, and hand-arm vibration syndrome), whereas others are vague or inclusive of a wide variety of less well-defined soft tissue disorders (i.e. repetition strain injury). For the purpose of clarity, we will provide a brief review of the terminology used in the literature. Critical evaluation of studies relating occupational exposures to soft tissue disorders will follow.

CARPAL TUNNEL SYNDROME This syndrome is characterized by neuritic symptoms, such as pain, paresthesias, and numbness in the cutaneous distribution of the median nerve. It is universally accepted that CTS is the clinical concomitant of compression of the median nerve as it passes through the carpal canal in the wrist. Physical signs include diminished sensibility to vibration and light touch in the cutaneous distribution of the median nerve, as well as abnormal two-point discrimination. Thenar muscle weakness and atrophy, as well as Phalen's sign (reproduction of hand symptoms following one minute of wrist flexion) or Tinel's sign (electric shock sensation radiating into the hand upon tapping the wrist), are classic findings in CTS. Electrodiagnostic studies are currently the "gold standard" for the evaluation of suspected CTS. Typical findings include prolongation of the distal motor latency of the median nerve, slowing of median sensory conduction velocity across the wrist, and denervation of the abductor pollicis brevis muscle (46, 83). Clinical signs and symptoms are not fully diagnostic of CTS. At this time, the best evidence for the sensitivity of clinical examination by a neurologist for the diagnosis of this syndrome is 84% with a specificity of 72% (44). The sensitivity and specificity of Tinel's sign were 0.60 and

0.67, respectively, and of Phalen's sign 0.75 and 0.47, respectively (44). Other studies of the sensitivity and specificity of these tests for the detection of CTS have found similar results (24, 32). At this time, most authorities agree that a combination of characteristic symptoms, signs, and electrodiagnostic findings is the most valid means of diagnosing this syndrome (23, 46, 65, 74, 81).

TENDINITIS Tendinitis and tenosynovitis refer to inflammation of the tendon and tendon sheath, respectively. Both are associated with painful impairment of motion involving the tendon. Tendon swelling, as well as crepitations, can be found on physical examination (13, p. 119). Tenosynovitis can progress to stenosing tenosynovitis, characterized by narrowing of the tendon sheath (48) and triggering movements of the digits ("trigger finger"). Although the most commonly affected tendons include the dorsal extensors of the wrist, the extensor carpi ulnaris, and the long abductor and short extensor of the thumb (de Quervain's disease) (13, p. 119), any muscle-tendon unit of the extremities can be affected (48). Some authors distinguish tendinitis from peritendinitis, which refers to inflammation of the muscle tendon junction and adjacent muscle tissue. The diagnosis is based on the presence of pain on palpation of the tendon, pain localized to the tendon on resisted movement, crepitations on palpation over the tendon, or the presence of warm, swollen tendons on palpation.

HAND-ARM VIBRATION SYNDROME This disorder of blood vessels and peripheral nerves is caused typically by use of hand-held vibrating tools (60). It also has been referred to as white finger, vibration white finger, occupational Raynaud's disease, and vibration syndrome (18). These terms all refer to a clinically and epidemiologically distinct disease entity. The vascular component of the disorder is characterized clinically by cold-induced vasospasm, indistinguishable from Raynaud's disease, and pathologically by hypertrophy of the medial muscular layer of the digital arterial wall and by perivascular fibrosis (60). The neurological component is characterized clinically by abnormal sensory and motor function and likely involves both nerve fibers and mechanoreceptors (66). Some controversy exists regarding the diagnostic distinction between the neurological component of hand-arm vibration syndrome and CTS, because both diffuse neuropathy and focal slowing of median nerve sensory conduction velocity at thc wrist have been found in symptomatic workers using vibrating tools (19).

CUMULATIVE TRAUMA DISORDER This term has been used commonly in the United States. Its origins can be found in Tichauer's classic review, in which he stated: ". . . industrial health care must consider a different kind of impairment caused insidiously over lengthy periods of time by gradual, cumulative, and often imperceptible overstrain of minute body elements." (86, p. 63) Armstrong (4) has defined cumulative trauma disorders as: "Those disorders of the muscles, tendons, nerves, and blood vessels that are caused, precipitated, or aggravataed by repeated exertions or movements of the body." Armstrong explicitly stated that the term cumulative trauma disorder is not meant to serve as a diagnosis, but that rather it refers to a class of disorders "with similar characteristics" including pathogenesis; documented relationship to exposure; chronicity of onset and response to treatment; symptoms that are often poorly localized, nonspecific, and episodic; and association with multiple occupational and nonoccupational factors (4). Armstrong noted a tendency for cumulative trauma disorders to be underreported and recommended the use of epidemiologic methods to isolate jobs, tools, areas, plants, or industries with excessive risk.

REPETITION STRAIN INJURY This term was popularized in Australia during the 1970s and 1980s when an apparent epidemic of diffuse arm pain was noted among a variety of occupational groups, including both those traditionally considered to be at risk for occupationally related musculoskeletal disorders, such as assembly line workers, and those previously thought to be at lower risk, such as clerical workers. The term was best defined by the Worksafe Australia—National Occupational Health and Safety Commission document "Repetition Strain Injury (RSI): A Report and Model Code of Practice":

> Repetition Strain Injury (RSI), also known as Occupational Overuse Syndrome, is a collective term for a range of conditions characterized by discomfort or persistent pain in muscles, tendons, and other soft tissues, with or without physical manifestations. Repetition Strain Injury is usually caused or aggravated by work, and is associated with repetitive movement, sustained or constrained postures and/or forceful movements. Psycho-social factors, including stress in the working environment, may be important in the development of Repetition Strain Injury. Some conditions which fall within the scope of Repetition Strain Injury are well-defined and understood medically, but many are not, and the basis for their cause and development is yet to be determined. It occurs among workers performing tasks involving either frequent repetitive and/or forceful movements of the limbs or the maintenance of fixed postures for prolonged periods, e.g., process workers, keyboard operators, and machinists. (62, p. 7)

The report acknowledged that the majority of cases were not well defined, and that the most notable feature of these cases was the reporting of upper extremity or neck pain.

OCCUPATIONAL CERVICOBRACHIAL DISORDERS This term refers to disorders of the neck and shoulder that have been related by some authors to occupational factors (38, 39, 89). Waris (89) has reviewed these disorders and included cervical syndrome, tension neck syndrome, humeral tendinitis, and thoracic outlet syndrome in this category. Cervical syndrome results from degenerative changes in the cervical spine. Tension neck syndrome, also referred to in the literature as tension myalgia, has been defined as a complex of pain, tenderness, and stiffness of muscles, coupled with the physical finding of muscle spasm. Humeral tendinitis refers to both supraspinous and bicipital tendinitis. Thoracic outlet syndrome is the result of neurovascular compression at the superior thoracic outlet. The term occupational cervicobrachial disorder was used extensively in Japan to describe an epidemic of work related shoulder and neck pain (54).

OVERUSE SYNDROME Overuse syndrome was characterized by Dennett & Fry (25) as "a musculoskeletal disorder characterized by pain, tenderness, and often functional loss in muscle groups and ligaments subjected to heavy or unaccustomed use." Fry (30) noted that pain is the predominant symptom and may occur in the hand and wrist area, forearm, elbow, shoulder area, scapular area, and neck. In addition, he described the possibility of sensory loss that can "mimic other conditions" (30, p. 728) and indicated that the disorder could arise bilaterally, even in the absence of symmetrical loading. Physical examination is positive for the condition when the patient experiences tenderness on palpation of the affected muscles, joints, and ligaments. Puffer & Zachazewski (67) provided a similar description of overuse syndrome.

REGIONAL MUSCULOSKELETAL ILLNESS This term has been championed by Hadler (36). He believes that the hypothesis that upper-extremity disorders are caused by occupational factors is unsubstantiated empirically. He argues that upper-extremity symptoms (the "predicament" of arm pain) are common. In addition, although he notes that discomfort of the upper extremities can be associated with occupational factors, he insists that upper-extremity musculoskeletal disorders that are characterized by a "dystrophic, atrophic, or overtly inflammatory state" (37, p. 39) have not been associated etiologically with work. He claims that the discomfort experienced by workers is best considered a form of "fatigue" (35) or "soreness" (37), rather than a workplace-induced musculoskeletal disorder.

Summary and Recommendations

One of the major impediments to diagnostic clarity and etiologic understanding of upper-extremity musculoskeletal disorders is widespread use of confusing and inconsistent terminology. A variety of terms have been introduced in the literature to allow reference to a heterogeneous group of upper-extremity musculoskeletal disorders that have in common an apparent increase in prevalence under certain occupational conditions. These terms include cumulative trauma disorder, repetition strain injury, occupational cervicobrachial disorder, and overuse syndrome. Despite the fact that some investigators have stated that these terms are synonymous, critical review of the literature fails to support this concept.

Another problem is that the terms repetition strain injury, cumulative trauma disorder, and occupational overuse imply etiology. There is not, however, substantial evidence that these disorders arise from cumulative trauma or that repetitive strain is the critical exposure. Indeed, the studies by Silverstein and colleagues (5, 77, 78), reviewed below, fail to show an increase in the prevalence these disorders with increasing work duration. The cross-sectional design of their studies may preclude observation of an exposure-response relationship as a result of survival bias or the effects of changing of job activities with increasing tenure; nevertheless, the available data certainly do not yet support the concept of "cumulative trauma."

If an all-inclusive term is required, the terms "musculoskeletal disorders of occupational origin" and "soft tissue disorders of occupational origin" seem more descriptive and should be applied to nonarticular musculoskeletal, vascular, and neurologic disorders for which significant elevations in risk are associated with occupational factors. For most applications, however, well-defined entities (i.e. CTS or tendinitis) should be used when attempting to relate occupational factors to musculoskeletal health outcomes. The term "upper-extremity pain syndrome" is recommended for those patients with upper-extremity pain who have symptoms that are not consistent with conventional diagnostic categories and normal physical examinations and physiological studies. Collective terms, such as RSI, are not diagnoses and should not be used in such cases.

EPIDEMIOLOGIC EVIDENCE FOR WORK RELATEDNESS

We review here the evidence for a causal relationship between workplace exposures and upper-extremity musculoskeletal disorders. We will summarize and critique the most rigorous studies aimed at testing the hypothesis that occupational exposures are causally associated with upper-extremity musculoskeletal disorders. In addition, we survey the voluminous literature that describes and characterizes the hand-arm vibration syndrome, a well-studied disorder caused by exposure to high frequency vibration. Finally, we will examine two poorly characterized disorders of the upper extremities, RSI and musculoskeletal discomfort among VDT users. For the purpose of this review, we have divided these disorders into "well-defined" and "poorly defined" categories.

Well-Defined Disorders

Carpal tunnel syndrome, tendinitis, and hand-arm vibration syndrome are the musculoskeletal disorders of the upper extremities that have most convincingly been associated with occupational factors. Well-defined disorders other than these, such as cervical radiculopathy, supraspinatus (rotator cuff) tendinitis, and epicondylitis, have been described in the orthopedic, rheumatologic, and occupational medicine literature, but at this time have not been so clearly associated with work.

CARPAL TUNNEL SYNDROME AND TENDINITIS Stock (84) has provided the most rigorous review of the literature to date that relates occupational exposures to upper-extremity musculoskeletal disorders. She performed an exhaustive literature search followed by critical evaluation and metaanalysis of those published studies that met well-defined criteria, including adequate definition of the study population; inclusion of an appropriate comparison group; appropriate measures of exposure; use of well-defined musculoskeletal endpoints that included objective physical signs of disease in addition to the presence of symptoms; and appropriate study design consisting of either case-control, cross-sectional, longitudinal cohort, or randomized controlled trial. She did not include studies of the hand-arm vibration syndrome. Of the 54 potentially relevant studies initially identified, Stock found that only five published papers and one Ph.D. thesis (5, 53, 59, 76, 77, 78) met the a priori criteria for inclusion. Stock then applied a series of validity tests to these studies and concluded that one of the initially identified papers on occupational CTS (59) should be excluded from the analysis because assessments of exposure in it were seriously flawed. The earliest of the four remaining published papers describes a study of Finnish assembly line packers in a food processing plant (53). The three remaining published papers were based on Silverstein's Ph.D. thesis (76) (see Table 2). We examine these four papers in some detail and also refer the reader to Stock's analysis (84).

Luopajarvi et al (53) performed an extensive upper-extremity evaluation on 152 female assembly line packers in a food processing plant and 133 female department store workers (excluding cashiers). Exposure assessment was not as rigorous as that employed by Silverstein and colleagues (described below), and was provided in the form of semiquantitative descriptions of the occupational tasks performed by both workers and referents. However, determination of health outcomes was rigorous and included assessment of both subjective symptomatology and physical examination findings. Waris et al (90) described in detail the methods used to diagnose neck and limb disorders. Their review retains considerable utility today. The major finding of the study was that "muscle-tendon syndrome," i.e. both tenosynovitis and peritendinitis of the hand and wrist flexors and extensors, was found in 56% of the assembly

Table 2 Exemplary papers relating workplace ergonomic factors to upper-extremity musculoskeletal disorders

Publication	Outcome(s)	Study population
Luopajarvi et al [49]	Tendinitis, tenosynovitis	163 female assembly line packers in a food production factory and 143 department store workers (excluding cashiers)
Silverstein et al [70]	Hand-wrist cumulative trauma disorders: tendinitis, tenosynovitis, de Quervains disease, trigger finger, carpal tunnel syndrome, Guyon tunnel syndrome, digital neuritis	574 active industrial workers in 6 plants performing 35 "jobs": electronics assembly, major appliance manufacturing, investment casting of turbine engine blades, apparel sewing, ductile iron foundry, bearing manufacturing
Silverstein et al [71]	Carpal tunnel syndrome	Same as above plus a second bearing manufacturing plant, for a total of 652 workers performing 39 "jobs"
Armstrong et al [5]	Tendinitis (subset of above disorders)	Same as above

line packers, compared with 14% of the department store workers. The authors concluded that this highly statistically significant excess disease in the process workers was due to occupational factors, including rapidity of the work, extremes of posture, static muscle loading, and high hand forces.

In the first of their papers, Silverstein and colleagues (77) investigated the association between two occupational factors—force and repetition—and tendon-related disorders (tendinitis, tenosynovitis, de Quervain's disease, and trigger finger) and peripheral nerve entrapments (CTS, Guyon tunnel syndrome, and digital neuritis). Measures of exposure included assessment of hand forces by use of surface electromyography and of repetitiveness by videotaping the work process on a sample of the 574 study participants. The video system also allowed evaluation of postural factors, such as wrist deviation and type of grasp. Jobs involving exposure to vibration were noted. General criteria for the diagnosis of musculoskeletal outcomes required that on interview subjects have symptoms of pain, numbness, or tingling; symptoms lasting more than one week or occurring more than 20 times in the previous year or both; no evidence of acute traumatic onset; no related systemic diseases; and onset since working on the current job. On physical examination, subjects were required to have the characteristic signs of muscle, tendon, or peripheral nerve lesions, although these were not specified in the paper. On both history and physical examination, 51 subjects had a condition that met the criteria for the upper-extremity disorders of interest. Men and women were not evenly distributed in exposure categories (high-force low-repetition, low-force high-repetition, and high-force high-repetition). In addition, there were differences in the distributions of exposure group and sex between plants. For example, there were, surprisingly, no women in the low-force low-repetition category in two of six plants, and no men in the high-force high-repetition category in two plants. To control for these potentially confounding effects, Mantel-Haenszel χ-square and logistic regressions analyses were performed. In particular, most analyses included adjustment for plant, which had a strong and inconsistent effect on the magnitude of the estimated odds ratios. For example, in analyses comparing high-force high-repetition men with low-force low-repetition men, the crude odds ratio was 27.1 and the plant-adjusted odds ratio was 4.9, whereas in corresponding analyses for both sexes combined the crude odds ratio was 17.2 and the plant-adjusted odds ratio was 30.3. The authors concluded that high force and high rates of repetition were positively associated with the musculoskeletal outcomes studied and that the combination of the two exposures increased the magnitude of the association more than either factor alone.

Silverstein et al (78) also investigated the association of the occupational factors force and repetition specifically with CTS. Methods were identical to those in the previous paper, except that data were included from a seventh industrial plant and the only outcome for which analyses were reported was CTS. Carpal tunnel syndrome was diagnosed when symptoms of pain, numbness, or tingling were present in the distribution of the median nerve and had occurred more than 20 times or had lasted more than one week during the previous year. A history of nocturnal exacerbation also was required. On physical examination, either Phalen's or Tinel's sign were required. Competing diagnoses, such as cervical radiculopathy, were identified on physical examination, and subjects with those diagnoses were excluded from the analysis. Twenty-five (3.8%) subjects met the criteria for classification as having CTS by history alone; 14 (2.1%) met the criteria by both history and physical examination. For those classified as CTS-positive by both history and physical examination, the crude odds ratio between high-force high-repetition and low-force low-repetition groups was 8.4, and the plant-adjusted odds ratio was 14.3. Odds ratios for high-force low-repetition and for low-force high-repetition groups relative to low-force low-repetition groups were not significantly greater than one, which indicated that force and repetition were synergistic risk factors for CTS.

Analyses associating upper-extremity tendinitis with force and repetition were reported as part of another paper published by Armstrong et al (5). The

29 cases of tendinitis reported are the same 29 cases of tendon-related disorders reported by Silverstein et al (77). A job-adjusted odds ratio for the development of tendinitis of 29.4 was reported for the high-force high-repetition group compared with the low-force low-repetition group. A crude odds ratio of 16.6 can be calculated from the data provided. Gender-specific odds ratios were not included, as they were in the two other published reports from essentially the same study, in which confounding by gender was suggested.

HAND-ARM VIBRATION SYNDROME This disorder, characterized by episodes of Raynaud-like vasospasm, as well as numbness and tingling of the fingers, results from exposure to hand-arm vibration (10, 18, 19, 33, 60). In the United States, Alice Hamilton first noted the condition among rock drillers (40). The United States Public Health Service estimates that 1.45 million American workers are at risk for this disorder (60). Occupations in which a high prevalence of disease has been found include grinders, forestry workers who use gasoline powered chain saws, and rock drillers. The occupational factor common to all affected populations is the use of tools that allow transmission of high frequency vibration to the hand and arm. Although objective measures of abnormal function are now becoming available, the current consensus staging system (10, 33) is based solely on symptoms of disease. This staging scheme allows for independent assessment of the severity of the vascular and neurological components of the syndrome, as they can occur independently of each other and can be of differing severity. The recent NIOSH document "Criteria for a Recommended Standard-Occupational Exposure to Hand-Arm Vibration" (60) recommends use of the staging scheme for surveillance of workers. Additionally, it recommends medical removal of workers with advanced stages as the primary method of protecting workers from this disorder.

A differential diagnostic issue of concern is the potential overlap in signs and symptoms between the hand-arm vibration syndrome and idiopathic CTS (18, 28). Although focal slowing of median nerve conduction velocity at the wrist suggestive of CTS has been described in vibration-exposed workers, a diffuse nerve and receptor pathology also is common in these workers (60, 66) and provides the basis for differentiating the two entities. It is unlikely, therefore, that the sensorineural symptoms prevalent among vibration-exposed workers are the result of vibration-induced CTS, as some authors propose (28).

Armstrong et al (6) have suggested that the chronic nerve disorder associated with use of vibrating power tools is due to focal nerve compression secondary to the high hand forces required by their use, as opposed to a direct neuropathic contribution of segmental hand-arm vibration. Indeed, because the two exposures—force and vibration—often occur concomitantly, separation of the effects of each is difficult. Nevertheless, a growing literature clearly indicates that vibration is etiologic in the development of both a vasospastic disorder of the upper extremity and a diffuse distal neuropathy. The neuropathy associated with vibration has been characterized both clinically and electrophysiologically (9, 11, 19, 60) and is unlike the focal nerve compression, i.e. CTS, that has been associated with the occupational factors force and repetition.

CRITIQUE The studies by Silverstein and colleagues are the best epidemiologic evaluations to date of the relationship between musculoskeletal disorders of the upper-extremity and occupational factors. They applied explicit operational definitions of health outcomes, including physical examination findings. The large sample size allowed powerful statistical tests on the results, and exposure characterization efforts were exemplary. The use of videotaped analysis of the work cycle to assess the repetitiveness of work and deviations of the joints (postural factors), as well as the use of electromyographic analysis of muscle activity to assess the force used by the subject, have greatly improved the validity of assessment of exposure. These methods of exposure assessment are, however, cumbersome and have been used to quantify exposures among only a small sample of the exposed population. For the future, the development of valid and more readily applicable measures of exposure will be valuable when performing large occupational epidemiologic studies.

Although the work of Silverstein and colleagues has shown that force and repetition are significant risk factors for tendinitis and CTS, their results suggest that other, unmeasured exposures or factors contribute to the development of these disorders. Specifically, the fact that the estimated odds ratios in analyses reported by Silverstein and colleagues changed substantially when they were plant-adjusted, implies that something differentially distributed among the plants not attributable to force and repetition category, gender, age, or current job tenure was associated with the outcomes being investigated. Although posture variables are often mentioned as risk factors for tendinitis and CTS, they were not found to be significantly associated with these outcomes in this study. The authors also noted that vibration was a confounder in this study, but they did not suggest that it was the exposure responsible for the plant effect. Inclusion of a plant effect to account for systematic effects of unmeasured variables improves the fit of the statistical model to the data observed in this particular study and reduces the statistical error to allow more powerful tests of the significance of other effects in the model (e.g. exposure category). However, inclusion of a plant effect in the statistical model may result in biasing thc estimates of the other parameters in the model. Furthermore, plant effects have no utility as predictor variables outside the study in which they are used, and odds ratios derived from models employing them should not be used to estimate risk in other exposure situations.

In the interest of rigorous definition of outcomes, all-inclusive terms, such as cumulative trauma disorder, should be avoided. As Silverstein and colleagues have done in recent published papers, outcomes should be restricted to individual clinical entities, such as CTS and tendinitis. To avoid misclassification of health outcome in future studies, researchers should employ quantitative, objective methods. For example, it is unclear how well, on clinical grounds alone, Silverstein et al were able to distinguish CTS from other nerve compression disorders, such as cervical radiculopathy, thoracic outlet syndrome, and pronator teres syndrome, which can cause similar symptoms and physical findings. The state-of-the-art for the diagnosis of CTS is electrodiagnostic evaluation coupled with appropriate signs and symptoms (23, 32, 44, 74, 81). Epidemiologic studies should employ, and the NIOSH surveillance case definition of CTS (16) should be modified to include, electrodiagnostic verification of median nerve disease at the wrist for all "cases." Unfortunately, electrodiagnostic studies are painful, and their administration requires a skilled technician and sophisticated equipment. Of great priority in this field is the development of nonaversive, noninvasive, objective methods for the identification and assessment of severity of entrapment neuropathies and other peripheral nerve disease.

Methods of objective assessment of exposure and health outcome are not as well established for hand-arm vibration syndrome as they are for tendinitis and CTS. Objective verification of the disease is needed, however, as the currently accepted staging system is based on symptoms. Specifically, objective, quantitative measures of both neurologic and vascular dysfunction must be validated and employed in worker surveillance programs. Regarding vibration exposure, substantial variability in measurements and interpretations of tool accelerations has led NIOSH to question their utility in disease prevention and to recommend that worker protection be based on disease surveillance (60). The utility of this worker protection strategy needs to be evaluated formally and compared with strategies that do not require overt disease as evidence of potentially dangerous exposure.

Finally, improvements in characterization of both outcomes and exposures need to be employed in prospective epidemiologic studies to overcome inherent limitations of the cross-sectional study design.

Poorly Defined Disorders

The previous section on well-defined disorders summarized the current knowledge regarding the work-relatedness of a group of musculoskeletal disorders (CTS, tendinitis, and hand-arm vibration syndrome) that are widely recognized as distinct clinical entities. A growing literature, much of which has emerged over the past decade from Australia, indicates that some workers also may be at risk for the development of upper-extremity problems that do not fit conventional medical categories and are controversial even regarding their existence. A marked increase in the diagnosis of repetition strain injury in Australia has had tremendous impact on both the practice of medicine and on the compensation system in that country. Unfortunately, little descriptive or analytic epidemiology is available to clarify issues of etiology or even to allow precise definitions of the disorder.

A related area of great current interest is that of the musculoskeletal effects reported to be associated with VDT use. Many of the workers in Australia diagnosed as having RSI were VDT operators. Considerable interest has emerged in the United States and elsewhere regarding this issue. Several municipalities, including New York City, have introduced legislation intended to protect VDT users from a variety of potentially adverse effects, including musculoskeletal disorders. The question is highly relevant as the estimated number of VDTs in use in the United States alone now exceeds 70 million (21).

REPETITION STRAIN INJURY Although descriptive epidemiology from Australia is incomplete, there have been indications that an apparent dramatic increase in the incidence of this disorder occurred there in the 1970s and 1980s. For example, reports of musculoskeletal diseases to compensation authorities in New South Wales, Australia, increased from 980 cases in 1978 to 4490 cases in 1983 (62). The most recent evidence indicates that the incidence of RSI peaked in 1985 and has since been decreasing rapidly (34, 43). Telecom Australia, a large telecommunications company, reported that 284 cases per 1000 clerical workers and 343 cases per 1000 telephonists occurred from 1981 to 1985 (42). The average duration of absence from work was 24 days. A marked decline in the incidence of RSI cases has occurred at Telecom since the peak of 600 new cases in the last quarter of 1984 to fewer than 25 new cases in the last quarter of 1988, a number almost identical to that for early 1981 (43).

The poorly defined nature of this disorder caused considerable controversy in Australia, and a variety of competing theories regarding its genesis have been published. Deves & Spillane (26) have reviewed four perspectives on the occurrence of this disorder:

1. Medical model: Workers are afflicted with a diagnosable physical condition that is causally related to the occupational ergonomic conditions.
2. Psychiatric model: Workers are afflicted with a conversion or a somatization disorder. Sufferers experience pain in the absence of organic disease.

3. Malingering model: Workers are not afflicted with either organic or psychiatric disorders. Rather, they are deliberately falsifying symptoms to achieve material benefits.
4. Patienthood model: Workers are part of a broad movement that provides "a convenient and socially acceptable medium through which discontent about the nature and conditions of work can be communicated symbolically, thereby facilitating personal coping."

Because both the existence and the work-relatedness of the condition have been questioned, McDermott (48) wrote of RSI: "There is no agreement concerning the cause; the pathology is unknown; the clinical features are diffuse; there are no useful diagnostic investigations; and the prognosis is uncertain." More recently, Hocking (43) has reported "The Royal Australasian College of Physicians has stated that the epidemic was not related to any injury as a result of work practices."

Many of the Australian workers who experienced work-related, upper-extremity pain failed to respond to conventional therapeutics, such as abstinence from occupational exposure, physical therapy, and anti-inflammatory medication (58). Pain often was incapacitating and out of proportion to physical findings. Many sufferers remained unable to return to employment for prolonged periods of time (42, 57).

Despite the lack of a unifying pathophysiological model for RSI, Browne et al (12) proposed a clinical staging system. Stage 1 disease is characterized by aching and tiredness of the affected limb, which occurs during the work shift and resolves overnight and on days off work. Physical signs are not present. Stage 2 symptoms are more intense during the workshift than are those of Stage 1, and fail to resolve overnight. Physical signs may be present. Stage 3 disease is characterized by aching, fatigue, and weakness, which are present at rest and occur following nonrepetitive movements. Physical signs are present. This stage of disease may persist for months or years. Browne et al provided no guidance regarding the specific physical signs that might be present.

MUSCULOSKELETAL DISCOMFORT AMONG VDT OPERATORS An issue of particular interest in the Australian experience was that a large proportion of symptomatic workers were employed in jobs that required the use of video display equipped data entry or word processing terminals (42, 58, 62). Experience at our occupational medicine clinic and information from representatives of both management and organized labor (50) indicate that a sharp rise in the frequency of reporting of soft tissue pain by VDT operators is occurring in the United States. Studies in the United States and elsewhere have attempted to relate symptoms of musculoskeletal discomfort to the use of VDTs, as well as to work organizational factors. We will discuss the largest of these studies.

In the earliest of these studies Smith et al (80) used a questionnaire to assess the frequency of musculoskeletal and other symptoms among clerical and professional workers who used VDTs and among nonusers. The VDT-exposed clerical workers were employed as data entry clerks, data retrieval clerks, classified advertising clerks, circulation and distribution clerks, and telephone inquiry clerks. Their work was described as highly regimented, with little operator control. The clerical nonusers were employed in jobs "identical to those of the clerical VDT operators, except that they did not use the VDT in performing their task. Their working conditions were almost identical to those of the clerical VDT operators" (80, p. 390). The professional VDT users were mainly reporters, editors, copy editors, and printers who had greater control over the structure of their workday. Clerical VDT users reported significantly more upper-extremity musculoskeletal discomfort than did either professionals who used VDTs or nonusers. Professionals using VDTs did not report more upper-extremity musculoskeletal discomfort than the nonusers. The response rate was low (less than 50%), and no measures of risk (e.g. odds ratio or relative risk) were presented. Formal ergonomic evaluations of workstations were not reported, and other exposure parameters, such as the number of hours per day spent typing or typing speed, were not described. In addition to reporting the most musculoskeletal discomfort, clerical workers also reported the highest stress levels, followed by the controls and professional VDT operators. Smith et al concluded that "there must be other factors beyond the physical presence of the VDT that contribute to the health complaints and stress level of the clerical operators. One such factor may be job content." Smith et al mention rigid work practices, high production standards, constant pressure for performance, absence of operator control, and little identification with and satisfaction from the end product of their work activities as contributory to the elevation in health complaints seen in the clerical VDT operators compared to professionals using VDTs.

Knave et al (47) performed a study of subjective symptoms and discomfort among 400 VDT operators and 150 referents in Sweden. Only those employees using VDTs more than five hours per day were eligible for inclusion in the exposed group. Little information was provided regarding the work tasks of the referents, and Knave et al used a questionnaire to measure both exposure and outcome. Musculoskeletal complaints were more common among the VDT operators than they were among the referents, but the differences were not statistically significant. When "complaint scores" were calculated for different anatomic regions, significant differences were observed between VDT operators and non-VDT users for the shoulder and back regions but not for hand, forearm, elbow, upper arm, and neck. There were reporting differences between men and women. Measures of risk were not presented. The authors concluded that VDT operators may possibly suffer from more musculoskeletal discomfort in their shoulders, neck, and back than do non-VDT users.

In a cross-sectional study, Rossignol et al (73) used a questionnaire to assess health outcomes among 1545 clerical workers. Subjects were employed in banking, communications, computer and data processing services, hospitals, public utilities, and civil service. Among all VDT users, the prevalence of musculoskeletal cases (any workers who reported experiencing one or more adverse musculoskeletal condition "almost always" or who missed work because of one of these conditions) increased with increasing average daily use of the VDT. Specifically, relative to nonusers, the prevalence ratios were 0.9 (90% CI 0.7–1.1) for subjects who used VDTs 0.5–3 hours per day, 1.2 (0.9–1.5) for the 4–6 hour per day group, and 1.8 (1.4–2.2) for the group that worked 7 or more hours per day. The authors considered this finding to be evidence for a dose-effect relationship. When stratified by specific musculoskeletal complaint, the prevalence of both neck and shoulder discomfort increased monotonically with increasing daily VDT use. The relationship between arm or hand pain and VDT use was not, however, so clear. The authors recommended restricting VDT use to three hours or less to decrease the frequency of discomfort and prevent any associated "chronic effects."

Stellman et al (82) performed a cross-sectional study of 1032 female office workers. They used a questionnaire to assess the relationship between office work, including the use of VDTs, and the development of a variety of health outcomes, including musculoskeletal symptoms. They used the occupational categories of part-day typist, full-day typist, part-day VDT user, full-day VDT user, and clerk. The factors measured included job characteristics, such as decision-making latitude and ability to learn new things on the job; characteristics of the physical environment, such as work station adjustability; visual and musculoskeletal symptoms; and job satisfaction. Full-day VDT users reported significantly more overall musculoskeletal discomfort than the other groups. Musculoskeletal symptom prevalence averaged over all exposure groups ranged from 10% to 30%, depending upon the specific anatomic regions. Full-day VDT users reported the highest levels of discomfort of the exposure groups for all musculoskeletal symptoms (hand cramps, arm and wrist pain, neck and shoulder pain, and back pain). Part-day VDT users did not report significantly different levels of musculoskeletal discomfort from nonusers. Interestingly, full-day VDT users had the lowest levels of job satisfaction in four of five such categories in the study and also complained of more discomfort related to their workstations. Stellman et al concluded that "automated office technology is associated with an increase in stressful working conditions and lower job satisfaction" and recommended integration of computer and noncomputer tasks as a strategy for reducing "the potentially stressful aspects of these jobs." They did not discuss the possibility that VDT workstations were selectively introduced into jobs that were more stressful or allowed less control over the work-process. Although their data are consistent with the idea that office technology increases the risk of musculoskeletal complaints, other explanations in which VDTs are markers for the real etiology of the health outcomes (i.e. stressful work) also are viable.

A NIOSH Health Hazard Evaluation (61) at a large daily newspaper also used a questionnaire to evaluate the relationship between work-related factors and symptoms of upper-extremity and neck discomfort in 834 employees, including reporters, editors, and classified advertisement salespersons. Of the group, 331 (40%) reported "symptoms consistent with upper-extremity cumulative trauma disorders" during the year preceding the study. Odds ratios estimated by using logistic regression techniques were 2.5 (95% CI 1.0–5.6) for hand/wrist symptoms and 4.1 (1.8–9.4) for shoulder symptoms among self-reported "fast" typists relative to nontypists. Odds ratios for the variable employment as a reporter/writer were 2.4 (1.6–3.4) for hand/wrist symptoms and 2.5 (1.5–4.0) for elbow/forearm symptoms. Percentage of time spent typing was significantly associated with elbow-forearm symptoms among those typing more than 80% of the time (OR = 2.8, 95% CI = 1.4–2.7) and neck symptoms for those typing 60%–79% of the time (OR = 2.2; 1.0–5.4), as well as for those typing 80%–100% of the time (OR = 2.8; 1.4–5.4). They concluded that a hazard for upper-extremity cumulative trauma disorders was present at the facility.

RECOMMENDATIONS The Australian epidemic of an apparently work-related upper-extremity pain syndrome that often is incapacitating and refractory to conventional therapy is of great concern. The disorder was diagnosed among industrial, clerical, and other populations. The diagnosis became so prevalent that it nearly caused collapse of the worker compensation system (26). Since 1985, a decrease in the incidence of RSI, almost as dramatic as the increase from 1981 to 1985, has occurred in some job categories (34, 43), but not in others (34). No consensus has emerged in Australia regarding the etiologies, pathogenesis, treatment, or prevention of this entity. Growing factionalization has arisen during the debate, with claims of fraud at one end of the spectrum and of profound medical epidemic at the other. Currently, there is growing acecdotal evidence that local epidemics of a similar poorly defined upper-extremity pain syndrome are becoming common in the United States. Given the potentially large number of workers at risk, an epidemic in the United States analogous to the one in Australia would have enormous impact on the public's health, the medical community, the compensation system, and the economy. The occupational medicine community should, therefore, demand high quality epidemiologic and clinical studies of this disorder.

Given the proliferation of VDTs in the workplace and current concern regarding their safety, it is remarkable that virtually no data are available regarding the prevalence of objectively verified musculoskeletal disorders among VDT users. Several large studies have found significant elevations of musculoskeletal discomfort among VDT operators and suggest that soft tissue disorders are associated with their use. Large, well-conducted studies that utilize well-defined objective measures of exposure and outcome are desperately needed to clarify these relationships.

CONCLUSIONS AND RECOMMENDATIONS

1. A consistent and well-defined nomenclature must be developed by consensus and used when describing work-related musculoskeletal disorders of the upper extremity and neck. To clarify the confusion in nomenclature, we suggest that an international panel of experts be assembled to recommend standard terminology for these disorders.

2. All-inclusive terms, such as repetition strain injury, cumulative trauma disorder, and occupational overuse syndrome, should be avoided. If such a term is required, we recommend musculoskeletal disorders of occupational origin. Occupational disease reporting systems should not utilize all-inclusive terminology. Specifically, we recommend that the US Bureau of Labor Statistics abandon the category "disorders associated with repeated trauma," which currently includes noise-induced hearing loss, hand-arm vibration syndrome, CTS, and tendinitis, and tabulate each of these distinct clinical entities separately.

3. Carpal tunnel syndrome, tendinitis and hand-arm vibration syndrome are etiologically related to occupational exposures. Sound epidemiologic studies utilizing quantitative measures of exposure and objective assessment of musculoskeletal outcomes have consistently found increased risks of these disorders in subjects who perform repetitive and forceful work, or who are exposed to hand-arm vibration.

4. Evidence for the work-relatedness of other musculoskeletal disorders of the upper extremities, such as epicondylitis, cervical radiculopathy, and thoracic outlet syndrome, is currently incomplete, although the available data often are suggestive of an occupational etiology.

5. Objective measures of musculoskeletal health outcome must be developed, validated, and used. The presence of pain alone is not necessarily synonymous with the presence of tissue damage or diagnosable soft tissue disorders. Of great priority in this field is the development of nonaversive, noninvasive, objective methods for the identification and assessment of severity of entrapment neuropathies and other peripheral nerve disease.

6. Measures of exposure should be explicit and quantified. Additional research to identify critical exposures, other than force, repetition, and vibration, must be performed. For the future, the development of valid and more readily applicable measures of exposure will be valuable when performing large epidemiologic studies of workers.

7. Clinical and epidemiological studies of the diffuse pain syndrome called "repetition strain injury" must be performed to clarify the extent and etiology of this problem. In particular, studies that include objective evaluation of musculoskeletal outcomes must be performed on VDT operators, the group in which this condition is most commonly described. In the absence of meaningful information about the entity labeled RSI, an unfortunate repetition of the Australian experience could occur in the United States.

SUMMARY

Sufficient evidence is available at this time to conclude that several well-defined soft-tissue disorders of the upper extremities are etiologically related to occupational factors. These disorders include tendinitis of the hand and wrist, CTS, and hand-arm vibration syndrome. Force, repetition, and vibration have been established as risk factors in the etiology of these disorders. Evidence exists that other, poorly understood factors also may contribute to etiology. At this time no firm guidelines can be established regarding maximum no-effect exposure levels. We agree, however, with Armstrong (3): "Although there are no standards for excessively repetitive or forceful work, common sense dictates that these tasks be minimized to the extent possible." Tool and job redesign may be required in many situations to accomplish these goals. In addition to appropriate reductions in risk factors, medical surveillance is required and will allow greater appreciation of the extent of this growing problem, as well as ongoing assessment of the efficacy of preventive intervention.

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