

Work-related musculoskeletal disorders: the epidemiologic evidence and the debate

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Abstract

The debate about work-relatedness of musculoskeletal disorders (MSDs) reflects both confusion about epidemiologic principles and gaps in the scientific literature. The physical ergonomic features of work frequently cited as risk factors for MSDs include rapid work pace and repetitive motion, forceful exertions, non-neutral body postures, and vibration. However, some still dispute the importance of these factors, especially relative to non-occupational causes. This paper addresses the controversy with reference to a major report recently commissioned by the US Congress from the National Research Council (NRC) and Institute of Medicine (IOM) (2001).

The available epidemiologic evidence is substantial, but will benefit from more longitudinal data to better evaluate gaps in knowledge concerning latency of effect, natural history, prognosis, and potential for selection bias in the form of the healthy worker effect. While objective measures may be especially useful in establishing a more secure diagnosis, subjective measures better capture patient impact. Examination techniques still do not exist that can serve as a “gold standard” for many of the symptoms that are commonly reported in workplace studies. Finally, exposure assessment has too often been limited to crude indicators, such as job title. Worker self-report, investigator observation, and direct measurement each add to understanding but the lack of standardized exposure metrics limits ability to compare findings among studies.

Despite these challenges, the epidemiologic literature on work-related MSDs—in combination with extensive laboratory evidence of pathomechanisms related to work stressors—is convincing to most. The NRC/IOM report concluded, and other reviewers internationally have concurred, that the etiologic importance of occupational ergonomic stressors for the occurrence of MSDs of the low back and upper extremities has been demonstrated.

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1. Introduction

“Musculoskeletal disorders” include a wide range of inflammatory and degenerative conditions affecting the muscles, tendons, ligaments, joints, peripheral nerves, and supporting blood vessels. These include clinical syndromes such as tendon inflammations and related conditions (tenosynovitis, epicondylitis, bursitis), nerve compression disorders (carpal tunnel syndrome, sciatica), and osteoarthritis, as well as less well standardized conditions such as myalgia, low back pain and other regional pain syndromes not attributable to known pathology. Body regions most commonly involved are the low back, neck, shoulder, forearm, and hand,

although recently the lower extremity has received more attention.

Musculoskeletal disorders (MSDs) are widespread in many countries, with substantial costs and impact on quality of life. Although not uniquely caused by work, they constitute a major proportion of all registered and/or compensable work-related diseases in many countries. Accurate data on the incidence and prevalence of musculoskeletal disorders are difficult to obtain, and official statistics are difficult to compare across countries. Nevertheless, MSDs are the single largest category of work-related illness, representing a third or more of all registered occupational diseases in the United States, the Nordic countries, and Japan [6,49,54,73]. Numerous surveys of working populations have reported upper extremity symptom prevalences of 20 to 30% or even higher. In the United States, Canada, Finland, Sweden, and England, musculoskele-

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tal disorders cause more work absenteeism or disability than any other group of diseases [4,15,39,54,63,65].

MSDs occur in certain industries and occupations with rates up to three or four times higher than the overall frequency. High-risk sectors include nursing facilities; air transportation; mining; food processing; leather tanning; and heavy and light manufacturing (vehicles, furniture, appliances, electrical and electronic products, textiles, apparel and shoes) [6]. Upper extremity musculoskeletal disorders are also highly prevalent in manual-intensive occupations, such as clerical work, postal service, cleaning, industrial inspection and packaging [63]. Back and lower limb disorders occur disproportionately among truck drivers, warehouse workers, airplane baggage handlers, construction trades, nurses, nursing aides and other patient-care workers, and operators of cranes and other large vehicles [54].

The physical job features that are frequently cited as risk factors for MSDs, based on both experimental science and epidemiologic investigations, include rapid work pace and repetitive motion patterns; insufficient recovery time; heavy lifting and forceful manual exertions; non-neutral body postures (either dynamic or static); mechanical pressure concentrations; segmental or whole-body vibration; local or whole-body exposure to cold; and any of these in combination with each other or with undesirable features of the psychosocial work environment like high demands and low degree of control over one's own work.

However, some authors still dispute the importance of these factors, especially relative to non-occupational causes. The debate about work-relatedness of MSDs reflects both confusion about epidemiologic principles and gaps in or disagreement about interpretation of the scientific literature.

Largely as a result of controversy within the United States about the relative importance of these risk factors, and the need for ergonomics regulations, the US Congress has twice commissioned an investigation of the relationship between MSDs and occupational factors. In 1998, the National Research Council (NRC) convened a workshop on work-related musculoskeletal disorders, at which the first author was an invited speaker. The charges to the multidisciplinary panel included “to evaluate contribution of jobs and job tasks ... to the occurrence of musculoskeletal disorders” of the lower back and upper extremities [48]. Again in January 1999, the NRC and Institute of Medicine (IOM) convened a panel on musculoskeletal disorders and the workplace, of which the second author was a member. This panel issued a second report [49] which substantially agreed with the first one, also reviewing literature from multiple fields and examining more formally the overall “patterns of evidence”. Here we discuss several of the key scientific

questions about the quality and interpretability of the epidemiologic evidence, with reference both to the 2001 NRC/IOM report, as well as to our own research experience.

1.1. Why does the debate continue?

While the epidemiologic literature has consistently implicated a common set of physical exposures, especially in workplace investigations, the magnitude of the association varies substantially among studies. Exposures are often dichotomized, and those exposure–response relationships that have been estimated are not always linear or monotonic. Variation in quantitative findings may result from differences in case definitions, operational definitions of ergonomic exposure, exposure-dependent latency periods, correlations among risk factors, or the range of exposures available for analysis.

Although these challenges exist, epidemiology is a critical component of the evidence because it is the only tool we have to evaluate whether laboratory findings have relevance in the “real world”. Experiments in biomechanics or tissue changes isolate the effects of individual exposures on specific outcomes and provide important information about mechanisms, dose patterns and recovery processes, and the shape of exposure–response curves. However, the endpoints are typically short-term responses that may or may not represent events on the causal pathway to the development of clinical syndromes. Epidemiology provides a way to determine whether the same exposures are associated with manifestations of disease over time intervals that correspond to meaningful induction periods. Furthermore, the true relationships between MSDs and workplace risk factors cannot be represented by a simple one-to-one mapping, since these features of work often co-occur—with common upstream determinants—and interact with each other. Epidemiologic investigations are required to describe and understand the effects of these mixed exposure profiles.

2. High background rate and multiple risk factors

As with most chronic diseases, MSDs have multiple risk factors, both occupational and non-occupational. In addition to work demands, other aspects of daily life, such as sports and housework, may present physical stresses to the musculoskeletal tissues. The musculoskeletal and peripheral nerve tissues are affected by systemic diseases such as rheumatoid arthritis, gout, lupus, and diabetes. Risk varies by age, gender, socioeconomic status, and ethnicity. Other suspected risk factors include obesity, smoking, muscle strength and other aspects of work capacity.

The NRC/IOM panel acknowledged—as do most authors—that the etiology of these disorders in the population as a whole is multifactorial. Not everyone with MSDs has ergonomic exposures at work, and not everyone exposed at work develops a MSD. The appropriate concept here is “work-related” disorders [90], as distinguished from specifically “occupational” disorders where a single factor is both necessary and sufficient to cause the disease (e.g. mesothelioma resulting from asbestos exposure).

Because these disorders are so common in the general population, and because of the many non-occupational risk factors, some have argued that occupational factors cannot account for a large proportion of the musculoskeletal disease burden in general. This is a non sequitur. The presence of one risk factor does not negate another. Whether occupational factors account for few or many MSDs in the *general* population is not the same question as to what extent people can be protected from preventable risks at work.

In fact, Tanaka et al. [77] estimated that about 40% of all upper extremity MSDs in the total US employed population were attributable to occupational exposures, representing over 500,000 people affected per year. This is an impressive figure, which is consistent with the NRC/IOM estimates of the proportions of MSD morbidity attributable to individual workplace factors among people exposed at work and thus amenable to prevention if those exposures were avoided (see Conclusions).

3. MSD case definitions

Outcome measures used in the literature include administrative data (e.g. compensation claims or absenteeism), clinical examinations or diagnoses, and self-reported symptoms. Data from administrative systems are incomplete because not all work-related MSDs are compensable or OSHA-recordable; in addition, substantial workplace under-reporting has been described [42,53,59,72,78]. Reporting at work is likely affected by differences in pain thresholds, cultural influences, psychosocial factors at work, employer receptivity, job insecurity and labor relations (among other factors) [3,44,56,67].

The limitations of available diagnostic technologies for MSDs have been discussed by others [41,85]. Diagnostic criteria are not standardized and are often inconsistent from one examiner to another, even though there are consensus documents for several upper extremity MSDs [28,62,75]. The lack of standardized case definitions in part reflects the constraints of the diagnostic categories relative to the wide variety of symptoms and signs reported by affected workers. Conditions with well-defined identifiable path-

ology, such as carpal tunnel syndrome (CTS) and spinal disc herniation, account for only a small proportion of all MSD morbidity. The reliability of physical examination for specific disorders, such as CTS and rotator cuff tendonitis, is also variable [43]. Self-reported symptoms or functional impairments may thus often be more informative than the available physical examination maneuvers. While objective measures may be especially useful in establishing a more secure diagnosis, subjective measures better capture patient impact. The use of self-reported symptoms to determine health status is not unique to the study of MSDs; a standardized questionnaire for the assessment of chronic pulmonary obstructive disease has been widely used for years.

On the other hand, reliance on self-reported symptoms has generated substantial discussion. Symptoms range from specific to non-specific; some individuals suffer severe pain and disability even though their findings do not conform to specific diagnostic entities such as CTS, rotator cuff tendinitis, or de Quervain's disease. Examination techniques still do not exist that can serve as a “gold standard” for many of the symptoms that are frequently reported in workplace studies [85]. Nevertheless, symptom reports are highly correlated with physical findings of MSDs, e.g. Refs.[5,30]; cases defined by symptoms and by physical findings show very similar associations with the ergonomic characteristics of subjects' jobs, e.g. Refs. [7,58,60,61,69,70]. High symptom prevalences correspond to frequency of workers' compensation claims and OSHA-recordable MSD incidents in the same jobs [72] and were predictive of seeking medical services for MSD conditions [89]. Two investigations have found that a subject with CTS symptoms was far more likely to have abnormal median nerve conduction velocity or latency than one who did not [7,46].

MSD symptoms are often intermittent and episodic, especially in the early stages. However, even when they do not correspond to defined clinical syndromes, they may be of major public health significance. Several studies have recently illuminated the social and economic impact of these disorders on affected individuals and their families, e.g. Refs. [17,33,45,55,80].

It is not uncommon for investigators to collect data on multiple endpoints in order to compare results and assess potential impact of these issues on the findings. In addition, one single diagnosis or case definition may not capture all of the relevant morbidity. For example, Bovenzi et al. [8] reported six different conditions, ranging from non-specific to very specific, that all occurred in excess among workers with high lifetime dose of segmental vibration.

The literature reviewed in the NRC/IOM report included a wide variety of outcome measures, ranging from self-reported symptoms to clinical evaluation to

administratively recorded incidents. All of these were candidates for inclusion in the review of evidence, including self-reported symptoms if they had been obtained in a standardized and reproducible manner.

4. Characterization of ergonomic exposures

Exposure assessment has too often been limited to crude exposure indicators such as job title or type of work, without examination of within- and between-group variability, leading to potential misclassification [21,81,93]. In order to generalize findings across jurisdictions and to inform prevention efforts, physical exposures should be quantified in terms of generic vectors such as force or vibration (see Chapter 6 of Ref. [49]).

Observing or measuring physical ergonomic stressors in the workplace would seem to be preferable to asking workers for their estimates of exposure, but both have potential disadvantages. For example, work postures or forces are often measured on only a single occasion, for a brief period (e.g. 10 min) per subject. These limited observations raise the possibility of misclassification if exposures are not constant over time. Furthermore, direct observation cannot be used to estimate past exposures.

Although the use of self-report is criticized by some, there are numerous epidemiologic risk factors (cigarette smoking, reproductive history, dietary intake, etc.) evaluated consistently by self-report. For most of these there is some evidence as to reproducibility but limited knowledge about validity. In each instance, a certain amount of misclassification can be tolerated as long as this is not clearly disproportionate between cases and non-cases, which would create exposure–response associations by artifact.

Similarly, self-reported ergonomic exposures, in general, appear to be adequate for many epidemiologic purposes. Several authors have reported moderate correlations between measures of physical ergonomic exposure derived from questionnaire data and the corresponding measured variables [2,47,79,84,92]. In several studies of VDU operators, duration of keyboard use was described consistently by people in the same jobs; differences between self-reported and observed keying times appeared to be non-differential with respect to case status [7,14,27,68].

While there is ample evidence of levels above which exposure increases the risk, it does not necessarily follow that there is no excess risk below those levels. Differences in exposure metrics make it difficult to compare findings across studies. Frequent use of categorical descriptors limits determination of whether or not there are safe exposure “thresholds.” Cut-points between “low” and “high” are generally established

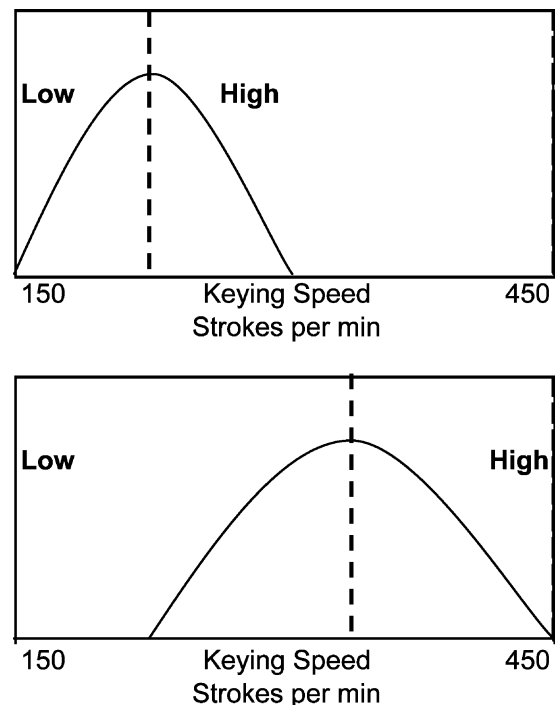


Fig. 1. Two hypothetical distributions of keying speeds, each categorized as “low” versus “high” for an epidemiologic study.

with reference to the exposure distribution within the particular population, so differences in these distributions between studies may have large effects on the exposure contrasts under study (Fig. 1). At the same time, increased risk in each “high” group (see figure) could be quite compatible with the same underlying exposure–response relationship.

Differences in exposure measures may also result in part from different conceptualizations of what is etiologically relevant. For example, a “low” level of muscular exertion would seem to be safer than a “high” level of force, but if the low force must be sustained for an excessive period of time, then the prolonged duration of the exertion may render it as hazardous as a brief, but more strenuous exertion [73]. Thus there is a need to understand better the specific effects of dynamic forceful motions, prolonged low-effort exertions, extreme postures, repetitive motion close to the center of the normal range, and the variety of other exposure profiles observed in jobs where MSDs occur.

The ergonomic stressors of non-cyclical work have received scant attention in comparison with highly repetitive work, which is inherently easier to analyze. This is unfortunate because limiting investigations to jobs with routinized tasks inherently reduces the variability in precisely some of the domains whose effects need to be studied.

Many methods for assessment of ergonomic exposures have been described; the challenge that exists at

the interface between ergonomics and epidemiology is to determine a level of exposure characterization effort that is efficient enough to permit analysis of inter-subject (and sometimes intra-subject) variability among hundreds of subjects and that can also produce exposure data at the necessary level of detail to examine etiologic relationships with musculoskeletal disease.

5. Epidemiologic design issues

The epidemiologic literature has been criticized by some because of the preponderance of cross-sectional and retrospective case-control investigations. Three salient features of these study designs are that, if employed in a workplace setting, cases are only counted among currently employed people; that cases of long duration are relatively over-represented; and that health and exposure data are collected simultaneously. The consequence of the first characteristic is that exposed persons who developed work-related MSDs may have left employment disproportionately (the “healthy worker effect”). Several studies have demonstrated that workers who develop musculoskeletal disorders in ergonomically stressful jobs are more likely to transfer to less exposed positions or to leave the workplace altogether [13,32,36,50–52,57,71,87]. This problem, which results from actual selection processes in the workplace, leads to an underestimate of the relationship with exposure and thus does not invalidate associations found between MSDs and workplace features.

Cross-sectional studies unavoidably over-sample disorders that last for a long time and are less likely to capture those that last only a short period. One could speculate that long-duration cases are either more or less sensitive to current exposures, but evidence is lacking as to whether these two groups in fact have different exposure–response relationships. On a separate but related point, it has been observed anecdotally, and in the limited body of prospective studies, that MSDs may develop after weeks, months, or years of exposure. The latency period required may be dependent on the intensity of exposure, but this also has not been well defined. The lack of data on these questions does not invalidate the extant literature, but raises uncertainty for some about how most appropriately to utilize the available epidemiologic evidence for establishing permissible exposure limits. Knowledge is also sparse as to the factors that predict recovery or persistence among workers who continue in exposed jobs after onset of disorders [12].

The consequence of concurrent data collection on exposures and health is an ambiguous temporal relationship between the two. A number of investigators have sought to remedy this ambiguity by restricting cases to those with onset after employment in the

job under study, or by collecting retrospective exposure histories. The literature cited above indicates that it is unlikely that MSDs would lead people to be more highly exposed at work; on the contrary, they often appear less exposed after onset than they would have if exposure information were collected before the health problem occurred. However, some are still troubled by the inability of such studies to confirm a fundamental aspect of etiology, namely, that cause precedes effect. The NRC/IOM report called particular attention to longitudinal studies, which do not suffer from this problem. It is important to note that, in general, the available longitudinal evidence has confirmed the conclusions previously drawn from cross-sectional studies regarding the associations between working conditions and MSDs.

Another important study design issue relates to whether or not study subjects are selected in a way that will provide an adequate range in the exposure(s) to be studied. Because there are many non-occupational risk factors, large and/or homogenous populations are required to address adequately the potential for confounding or effect modification of exposure–response relationships. Thus investigators must select populations carefully to obtain sufficient range in multiple covariates, and sufficiently uncorrelated distributions, even while gaining access to working populations is becoming increasingly difficult.

The separate and joint distributions of exposures within a study population determine the statistical power available to examine the effect of each one. For example, if age is highly correlated with seniority, as is often the case, it may not be feasible to determine the contribution of either one while adjusting statistically for the effect of the other, and it is important that the investigator not be misled in this matter by the ability of a statistical analysis program to compute *p*-values.

Failure to pay attention to this issue may lead to incorrect conclusions about the study’s ability to find evidence relating to a specific risk factor. As a consequence, it will also limit the utility of the data when attempting to partition the risk of disease among (related) exposures. Such estimation of attributable risk is seen as having important implications for selecting which exposures to intervene on, either within a workplace or at a higher level, such as through national regulation.

One arena where this problem is frequently seen is in the argument about the proportion of MSD morbidity that is due to physical or psychosocial risk factors. Leaving aside conceptual differences in how investigators define “psychosocial”, an even more fundamental issue is that these two domains share a common upstream determinant. The organization of the work process (who does what, how often, and how) involves a variety of specific decisions regarding task structure,

division of labor, and skill utilization. Thus work organization influences both the physical load patterns (work pace, repetitiveness, rest breaks) and psychosocial features such as job demands (work pace) and low decision latitude or skill utilization (monotony). For example, low job control may represent both the inability to modify or vary work pace or task sequencing when musculoskeletal discomfort occurs and a psychological stressor that impacts negatively on physiological homeostasis. Further complicating this problem, items such as “low job satisfaction” may represent a tautological outcome of physical or psychosocial strain at work and/or the experience of MSD pain while working.

High correlations between physical and psychosocial stressors have been shown [40] and might also be expected as a result of overlapping measurement constructs. In the Job Content Questionnaire, a widely used instrument for assessing psychosocial job strain, “psychological job demands” are measured by items that include “working hard” and “working fast”. Both piece-rate wages and machine-paced work are forms of work organization that are found in a highly specialized and segmented work process, associated with both stereotyped physical motion patterns and adverse psychosocial conditions such as low decision latitude and skill utilization. Such work organization features that imply rapid motions without rest breaks—and which have been associated with elevated risk of MSDs—include piece-rate versus hourly wages [9]; work without rest breaks or task change [66]; and just-in-time production [38]. Intervening on the up-stream organizational characteristics could be expected to reduce the morbidity occurring through both the physical and psychosocial pathways, whether or not they are independent of each other.

6. Conclusions

Despite the challenges discussed above, most reviewers agree that the epidemiology linking physical ergonomic exposures at work with risk of MSDs is methodologically adequate to inform primary prevention. The sheer scope of the literature is extraordinary; about 2500 articles met the search criteria established by the NRC/IOM panel. Of these, the reviewers relied most heavily upon about 170 studies, which is in itself an impressive body of literature.

After accounting for age, gender, body mass index, smoking, recreational activities, systemic disease, and other individual characteristics, the reviewers still found impressive associations between MSDs and occupational exposure to physical stressors. These findings were summarized in part by means of the attributable fraction (AF) for each exposure, as a range of

estimates across the studies that examined it. The AF is an estimate of the proportion of disease that would be reduced in the exposed population if the exposure were eliminated and represents the relative importance of exposure reduction in those settings where the exposure is prevalent. For physical stressors affecting the back, the AF was as high as 66% for manual material handling and 80% for whole-body vibration among exposed groups (Table 1), whereas the effects of psychosocial stressors were generally less pronounced (Table 2). The corresponding ranges for upper extremity disorders were as high as about 95% for segmental vibration or repetitive motion combined with other stressors (Table 3). Certain “psychosocial” stressors, especially high job demands, low decision latitude, and few rest breaks, were nearly as high, although fewer studies were available (Table 4).

Although some specific exposure–response relationships have not been demonstrated and more research is needed in several areas, there is evidence that exposure to each of these ergonomic factors causes MSDs in one or more body regions: repetitive upper extremity motion patterns; forceful exertions, whether manual only or whole-body (e.g. heavy lifting); non-neutral body postures; and vibration. The risk is especially pronounced when a job includes exposure to a combination of two or more of these risk factors. In combination with extensive laboratory evidence of pathomechanisms by which physical stressors injure the musculoskeletal system, e.g. Refs. [1,19,48,49,74], the epidemiologic evidence is biologically plausible.

Among the conclusions of the NRC/IOM report were that:

4. The weight of the evidence justifies the identification of certain work-related risk factors for the occurrence of musculoskeletal disorders of the low back and upper extremities (p. 364);

6. Modification of [those] physical and psychosocial factors could reduce substantially the risk of symptoms for low back and upper extremity disorders (p. 365); and

Table 1
Attributable fractions for occupational physical risk factors and the occurrence of back disorders

Risk factor	Null (n)	Positive (n)	AF% (range)
Manual material handling	4	24	11–66
Frequent bending and twisting	2	15	19–57
Heavy physical load	0	8	31–58
Static work posture	3	3	14–32
Whole-body vibration	1	16	18–80

Adapted from Table 4.2 of Ref [49].

Table 2

Attributable fractions for occupational psychosocial risk factors and the occurrence of back disorders

Risk factor	Null (<i>n</i>)	Positive (<i>n</i>)	AF% (range)
High job demands (work pace)	1	5	21–48
Monotonous work	2	4	23
Low social support at work	0	7	28–48
Low job satisfaction	1	13	17–69
High perceived stress	0	3	17
Low decision latitude/control	0	2	–
High perceived emotional effort	0	3	–
Perceived ability to return to work	0	3	–
Perceived work dangerous to back	0	2	–

Adapted from Table 4.4 of Ref. [49].

8. The weight of the evidence justifies the introduction of appropriate and selected interventions...to reduce physical as well as psychosocial stressors...[through] the development of integrated programs that address equipment design, work procedures, and organizational characteristics (p. 365).

The epidemiologic evidence associating the development of MSDs with workplace exposure to biomechanical and psychosocial factors has also been reviewed by the Musculoskeletal Committee of the International Commission for Occupational Health [31], the US National Institute for Occupational Safety and Health [6], the European Agency for Safety and Health at Work [10], and the SALTSA Joint Programme for Working Life Research in Europe [75]. Numerous peer-reviewed authors have concurred that the epidemiologic evidence demonstrates the etiologic importance of occupational ergonomic stressors for MSDs of the low back and upper extremity [1,11,16,18,20,22–26,29,34,37,64,76,82,83,86,91,94]. Many of them have called attention to methodologic issues such as those discussed here, and again there is a general consensus

Table 3

Attributable fractions for occupational physical risk factors and the occurrence of upper extremity disorders

Risk factor	Null (<i>n</i>)	Positive (<i>n</i>)	AF% (range)
Repetition	4	4	53–71
Force	1	2	78
Repetition and force	0	2	88–93
Repetition and cold	0	1	89
Vibration	6	26	44–95

Adapted from Table 4.3 of Ref. [49].

Table 4

Attributable fractions for occupational psychosocial risk factors and the occurrence of upper extremity disorders

Risk factor	Region	Null (<i>n</i>)	Positive (<i>n</i>)	AF% (range)
High job demand	All	6	10	33–58
	Elbow/arm	3	6	50–58
	Shoulder	6	6	33–47
Low decision latitude	Wrist	4	5	37–56
	All	10	6	37–64
	Elbow/arm	5	1	64
Low social support	Shoulder	8	6	37–47
	Wrist	8	3	37–84
	All	7	7	28–52
Few rest break opportunities	Elbow/arm	5	0	–
	Shoulder	7	5	–
	Wrist	4	3	28–52
	All	3	3	33–70
	Elbow/arm	1	1	67
	Shoulder	3	1	70
	Wrist	5	2	33

Adapted from Table 4.6 of Ref. [49].

that the overall consistency of the evidence outweighs the limitations of some individual studies.

Although the NRC/IOM report did not address the more limited evidence concerning arthrosis and other disorders of the hip and knee, evidence has also begun to accrue showing that similar exposures have similar effects on the soft tissues of the lower extremity [35,88].

Thus there is an international near-consensus that musculoskeletal disorders are causally related to occupational ergonomic stressors, such as repetitive and stereotyped motions, forceful exertions, non-neutral postures, vibration, and combinations of these exposures. A number of government and non-governmental agencies have codified this evidence in the form of ergonomics rules designed to prevent work-related MSDs, among them the American Conference of Governmental Industrial Hygienists (1999+); the European Agency for Safety and Health at Work, EU (1999); the SALTSA Joint Programme for Working Life Research in Europe (2000); and the Washington State Department of Labor and Industries (2000). A sizable proportion of MSDs among exposed workers are preventable, and protective action is both warranted and necessary.

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Laura Punnett earned a Doctor of Science degree from the Harvard School of Public Health in occupational health and epidemiology and completed her post-doctoral training in occupational ergonomics at The University of Michigan. She was a founding member of the Department of Work Environment at the University of Massachusetts Lowell, where she is now Professor of Occupational Epidemiology and Ergonomics. Her other positions at U.Mass. Lowell are Co-Director of the Lorin Kerr Ergonomics

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Dr. Punnett's primary research experience concerns work-related musculoskeletal disorders, along with the effect of ergonomic stressors on health endpoints, such as acute injury and pregnancy outcomes. More recently, she has turned to exploring a broader range of health effects that manifest a socioeconomic gradient and how much of that gradient might be explained by differential exposures to occupational stressors. A related issue is the variety of ways that occupational gender segregation and task specialization, whether formal or de facto, create differences in the physical, psychosocial and organizational conditions that women and men experience at work. Dr. Punnett is also interested in strategies for analysis of non-routinized jobs and the factors influencing the effectiveness of ergonomic intervention programs and joint labor-management health and safety committees.

Dr. Punnett serves on a number of advisory and scientific review committees. She is on the editorial boards of the journals *Applied Ergo-*

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David H. Wegman was recently appointed Dean of the new School of Health and Environment at the University of Massachusetts Lowell after 16 years as Professor and founding Chair of the Department of Work Environment. He also serves as Adjunct Professor at the Harvard School of Public Health and the University of Massachusetts Medical School. He received his BA from Swarthmore College, and his MD and MSc from Harvard University and is Board Certified in Preventive Medicine (Occupational

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Dr. Wegman has focused his research on epidemiologic studies of occupational respiratory disease, musculoskeletal disorders, and cancer and has published over 200 articles in the scientific literature. He has also written on public health and policy issues concerning hazard and health surveillance, methods of exposure assessment for epidemiologic studies, the development of alternatives to regulation and the use of participatory methods to study occupational health risks. He is co-editor with Dr. Barry Levy of one of the standard textbooks in the field of occupational health, *Occupational Health: Recognition and Prevention of Work-Related Disease*, the fourth edition of which was published by Lippincott, Williams and Wilkins in 2000. His recent work has focused on the examination of health and safety risks among construction workers involved in the building of the Third Harbor Tunnel and the underground Central Artery in Boston,

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Dr. Wegman is board-certified in Occupational Medicine, and a Fellow of the American College of Epidemiology, he serves as Treasurer of the International Epidemiological Association and has served as a member of the Board of Directors of the International Commission on Occupational Health and past Chair of its Scientific Committee on Epidemiology in Occupational Health. Currently he is chair of the National Research Council–Institute of Medicine (IOM) Committee on Health and Safety Needs of Older Workers and previously chaired the Committee on the Health and Safety Consequences of Child Labor. He has also been a member of the NRC-IOM Panel on Musculoskeletal Disorders and Work, the IOM Committees to Review the Health Consequences of Service During the Persian Gulf War and to Review Gender Differences in Susceptibility to Environmental Factors.

Dr. Wegman's government service has included Chair of the US Mine Safety and Health Administration's Advisory Committee on the Elimination of Pneumoconiosis Among Coal Mine Workers, member of the OSHA Standards Advisory Committee on Metal Working Fluids, consultant to the Director of NIOSH on the agency extramural research program and on research concerning aging and work. He has also served on the NIOSH Board of Scientific Counselors and the EPA Scientific Advisory Board. He serves as Chair of the Epidemiology Review Board for DuPont Corporation, and was past chair of the Occupational Health Advisory Board for the United Auto Workers and the General Motors Corporation.

Dr. Wegman is co-editor of Lippincott Williams and Wilkins introductory text, *Occupational Health: Recognition and Prevention of Work-Related Disease*, now in its fourth edition. He is an Associate Editor for the *American Journal of Industrial Medicine*, a member of the Editorial of the *Epidemiology Monitor*, the *International Journal of Occupational and Environmental Health* and *New Solutions*. He received the Alfred L. Frechette Award from the Massachusetts Public Health Association, and the Harriet L. Hardy Award from the New England College of Occupational and Environmental Medicine and was named as a Fulbright Scholar in 1998 for studies in Sweden on aging and work.