CHAPTER 4
Elbow Musculoskeletal Disorders (Epicondylitis): Evidence for Work-Relatedness

SUMMARY

Over 20 epidemiologic studies have examined physical workplace factors and their relationship to epicondylitis. The majority of studies involved study populations exposed to some combination of work factors, but among these studies were also those that assessed specific work factors. Each of the studies examined (those with negative, positive, or equivocal findings) contributed to the overall pool of data to make our decision on the strength of work-relatedness. Using epidemiologic criteria to examine these studies, and taking into account issues of confounding, bias, and strengths and limitations of the studies, we conclude the following:

There is **insufficient evidence** for support of an association between repetitive work and elbow musculoskeletal disorders (MSDs) based on currently available epidemiologic data. No studies having repetitive work as the dominant exposure factor met the four epidemiologic criteria.

There is **evidence** for the association with forceful work and epicondylitis. Studies that base exposure assessment on quantitative or semiquantitative data tended to show a stronger relationship for epicondylitis and force. Eight studies fulfilling at least one criteria showed statistically significant relationships.

There is **insufficient evidence** to draw conclusions about the relationship of postural factors alone and epicondylitis at this time.

There is **strong evidence** for a relationship between exposure to a combination of risk factors (e.g., force and repetition, force and posture) and epicondylitis. Based on the epidemiologic studies reviewed above, especially those with some quantitative evaluation of the risk factors, the evidence is clear that an exposure to a combination of exposures, especially at higher exposure levels (as can be seen in, for example, meatpacking or construction work) increases risk for epicondylitis. The one prospective study which had a combination of exposure factors had a particularly high incidence rate (IR=6.7), and illustrated a temporal relationship between physical exposure factors and epicondylitis.

The strong evidence for a combination of factors is consistent with evidence found in the sports and biomechanical literature. Studies outside the field of epidemiology also suggest that forceful and repetitive contraction of the elbow flexors or extensors (which can be caused by flexion and extension of the wrist) increases the risk of epicondylitis.

Epidemiologic surveillance data, both nationally and internationally, have consistently reported that the highest incidence of epicondylitis occurs in occupations and job tasks which are manually intensive and require high work demands in dynamic environments—for example, in mechanics, butchers, construction workers, and boilermakers.

Epicondylar tenderness has also been found to be associated with a combination of higher levels of forceful exertions, repetition, and extreme postures of the elbow. This distinction may not be a true demarcation of different disease processes, but part of a continuum. Some data indicate that a high

percentage of individuals with severe elbow pain are not able to do their jobs, and they have a higher rate of sick leave than individuals with other upper extremity disorders.

INTRODUCTION

Epicondylitis is an uncommon disorder, with the overall prevalence in the general population reported to be from 1% to 5% [Allender 1974]. There are fewer epidemiologic studies addressing workplace risk factors for elbow MSDs than for other MSDs. Most of these studies compare the prevalence of epicondylitis in workers in jobs known to have highly repetitive, forceful tasks (such as meat processing) to workers in less repetitive, forceful work (such as office jobs); the majority of these studies were not designed to identify individual workplace risk factors.

The text of this section on epicondylitis is organized by work-related exposure factor. The discussion within each factor is organized according to the criteria for evaluating evidence for work-relatedness in epidemiologic studies using the strength of association, the consistency of association, temporal relationships, exposure-response relationship, and coherence of evidence. Conclusions are presented with respect to epicondylitis for each exposure factor. Summary information relevant to the criteria used to evaluate study quality is presented in Tables 4-1 to 4-4. A more extensive summary (Table 4-5) includes information on health outcomes, covariates, and exposure measures. All tables are presented at the end of this chapter. Not all the articles summarized in the tables are referenced in this narrative, but they have been reviewed and evaluated and are included for information.

There are 19 studies referenced in Tables 4-1 through 4-4, 18 cross-sectional studies and one cohort. Those studies using symptom and physical examination findings to define epicondylitis used consistent criteria—almost all studies using physical examination for diagnosis required pain with palpation of the epicondylar area and pain at the elbow with resisted movement of the wrist. However, studies using a definition based on symptom data alone used various criteria, some based on frequency and duration of symptoms [Burt et al.1990; Hoekstra et al. 1994; Fishbein et al. 1988] others based on elbow symptoms preventing work activities [Ohlsson et al. 1989].

REPETITION

Definition of Repetition for Elbow MSDs

For our review, we chose studies that addressed the physical factor of repetition and its relation to elbow MSDs, especially those studies that focused on epicondylitis. Studies usually defined repetition, or repetitive work, for the elbow as work activities that involved (1) cyclical flexion and extension of the elbow or (2) cyclical pronation, supination, extension, and flexion of the wrist that generates loads to the elbow/forearm region. Most of the studies that examined repetition as a risk factor for epicondylitis had several concurrent or interacting physical work load factors. We attempted to select those studies in which repetition was either the single risk factor or the dominant risk factor based on our review of the study and our knowledge of the occupation. This method eliminated those studies in which a combination of high levels of repetition and high levels of force exist, or those studies which selected their exposure groups based on highly repetitive, forceful work.

Studies Reporting on the Association of Repetition and Epicondylitis

Seven studies reported results on the association between repetition and adverse elbow health outcomes including epicondylitis. The epidemiologic studies that address repetitive work and epicondylitis compare working groups by classifying them into categories based on some estimation of repetitive work, such as percent of time typing [Burt et al. 1990], number of items per hour [Ohlsson et al. 1989], or number of hand manipulations per hour [Baron et al. 1991]. Those studies which may have measured repetitive work but have exposure to higher levels of force will be discussed in the "Force" section.

Studies Meeting the Four Evaluation Criteria

None of the studies (see Table 4-1 and Figure 4-1) reviewed for the elbow summary section met all four evaluation criteria outlined in the Introduction Section.

Studies Meeting at Least One of the Criteria

The studies will be summarized in alphabetical order as they appear in Table 4-1.

Andersen and Gaardboe [1993a] used a cross-sectional design to compare sewing machine operators with a random sample of women from the general population of the same region. Elbow pain, not epicondylitis, was the MSD of interest in this study. A case of elbow pain was based on self-reported symptoms lasting more than 1 month since starting career, or pain for more than 30 days. Exposure was based on the authors' experiences as occupational health physicians and involved crude assessment of exposure level and exposure repetitiveness. Analysis dealt with exposure as "duration of exposure as a sewing machine operator". Statistical modeling controlled for age, having children, not doing leisure exercise, smoking, and socioeconomic status. For this study, the exposure classification scheme does not allow separation of the effects of repetition from those of force, although repetition may be a more obvious exposure.

Baron et al. [1991] explored epicondylitis among grocery store workers, comparing the prevalence among grocery store cashiers to that among non-cashiers and identified work risk factors while controlling for covariates. Detailed ergonomic assessment of grocery checking and cashiering was completed using both on-site observational techniques and videotaped analyses. The majority of cashiers were categorized as having "medium" levels of repetition for the hand (defined in this study as making 1250 to 2500 hand movements per hour). Repetitive movements were not recorded directly for the elbow; however, the number of hand movements serve as an approximation for elbow repetitions. Age, hobbies, second jobs, systemic disease, and height were considered as covariates in the multivariate analyses. The diagnosis of epicondylitis required standard physical examination techniques of palpation and resisted extension and flexion of the elbow.

Burt et al. [1990] studied 834 employees using computers at a metropolitan newspaper, using a self-administered questionnaire for case ascertainment. Exposure assessment was based on self-reported typing time and observation of employees' job tasks, then categorization by job title. A separate job analysis using a checklist and observational techniques was carried out for validating questionnaire exposure data. Workers fulfilling the case definition for elbow/forearm pain were compared to those who did not fulfill the case definition. Prevalence of cases was associated with percent of time typing and typing speed. Logistic regression controlled for age, gender, metabolic disorders, and job satisfaction.

Automobile assembly line workers were compared to a randomly selected group from the general population in the study by Byström et al. [1995]. A case of epicondylitis required symptoms and physical examination. "Job title" was used as a surrogate for exposure in the analysis. No assessment of repetition or repetitive work was completed specifically for the elbow.

McCormack et al. [1990] had a randomly selected population of 2,261 textile workers from over 8,000 eligible workers. Workers were analyzed by job category, after observation of jobs. Epicondylitis case ascertainment was by clinical exam. Of the 37 cases of epicondylitis identified, 13 were categorized as mild, 22 were moderate, and 2 were severe. Eleven examiners may have introduced an interexaminer reliability problem. Age, gender, race, and years of employment were analyzed as confounders.

Ohlsson et al. [1989] studied electrical equipment and automobile assemblers, former assembly workers and compared these two groups to a random sample from the general population. A case of elbow pain was based on questionnaire responses; exposure was based on job categorization as well as questionnaire responses. Repetitive exposure was based on a self-reported frequency of task items completed per hour (work pace). Results showed no association with work pace and elbow symptoms, and no association between length of employment and elbow symptoms.

Punnett et al. [1985] compared neck/shoulder MSDs based on symptom reporting alone in 162 women garment workers and 76 women hospital workers such as nurses, laboratory technicians, and laundry workers. There was a low participation rate among the hospital workers. Eighty-six percent of the garment workers were sewing machine operators and finishers (sewing and trimming by hand). The sewing machine operators were described as using highly repetitive, low force wrist and finger motions, while the finishers had shoulder and elbow motions as well. The exposed garment workers likely had more repetitive jobs than most of the hospital workers.

Strength of Association—Repetition and Elbow MSDs

No studies met the four criteria to discuss strength of association.

Strength of Association—Studies Not Meeting the Four Criteria

For the other studies not fulfilling all the criteria, the odds ratio (OR) reported in the

Baron et al. [1991] study for epicondylitis overall was 2.3, but this was not statistically significant.

Anderson and Gaardboe [1993a] used years employed as a sewing machine operator as a surrogate for exposure and found no significant association with epicondylitis.
None of the other studies that looked at epicondylitis among working groups carried out independent exposure assessment of workers or representative workers that focused on the elbow.

Burt et al. [1990] found a statistically significant OR of 2.8 for elbow/forearm symptoms in newspaper employees who reported typing 80%–100% of their working day compared to those typing 0%–20%. (Typing hours has been used as a surrogate of both repetition and duration of exposure.)

Likewise, Punnett et al. [1985] found a significant prevalence rate ratio (PRR=2.4) of persistent elbow symptoms among garment workers performing repetitive, forceful work compared to hospital workers. Analysis by job title showed that underpressers, whose jobs consisted of ironing by hand, had a PRR of 6.0. Among stitchers (sewing machine operators), the significant PRR for the task of setting linings was 7.7. When standardized to the age distribution of the hospital workers, the rate ratio did not change.

McCormack et al. [1990] and Ohlsson et al. [1989] based exposure on job title and found no association between repetitive work and epicondylitis, with non-significant ORs between 0.5 and 2.8.

Temporal Relationship—Repetition and Epicondylitis

There were no prospective studies which addressed repetition as a physical factor alone; all the studies were cross-sectional, so a temporal relationship cannot be established. However, some cross-sectional studies allow us to infer causality by use of restrictive case definitions. Studies by the National Institute for Occupational Safety and Health (NIOSH) investigators [Burt et al. 1990; Baron et al. 1991] excluded from analysis those workers who reported symptoms experienced prior to their present job and those with acute injury to the elbow not related to the job.

Consistency in Association for Repetition and Epicondylitis

The studies were not consistent in showing an association between repetitive work and epicondylitis. In terms of strength of association, there were no studies that had statistically significant ORs greater than 3.0, four studies had ORs between 1.0 and 3.0, that were statistically significant; and two studies had nonsignificant ORs less than 1.0.

Coherence of Evidence for Repetition

The evidence for epicondylitis in the biomechanical and sports literature does not address repetition alone, but has consistent evidence with a combination of forceful exertion, awkward or extreme postures, and repetitive movements. Please refer to the discussion under Coherence of Evidence for Force.

Exposure-Response Relationship for Repetition

In Baron et al.'s [1991] study, there was a dose-response relationship for the elbow for the number of hours per week working as a checker, with ORs up to around 3.0, but not for the duration of employment (the average length of employment was 8 years).

Conclusions Regarding Repetition

There is insufficient evidence for support of an association between repetitive work and elbow MSDs based on currently available epidemiologic data. There were no studies that met the four criteria. Of the 7 studies examining repetitive work, no studies found ORs above 3.0, 5 studies found ORs from 1–3, and 2 studies found an OR less than one.

FORCE

Definition of Force for Elbow MSDs

For our review, we included studies that examined force or forceful work or heavy loads to the elbow, or described exposure as strenuous work involving the forearm extensors or flexors, which could generate loads to the elbow/forearm region. Most of the studies that examined force or forceful work as a risk factor for epicondylitis had several concurrent or interacting physical workload factors.

Studies Reporting on the Association of Force and Epicondylitis

Thirteen studies reported results on the association between force and adverse elbow health outcomes, including epicondylitis. The epidemiologic studies that addressed forceful work and epicondylitis compared working groups by classifying them into broad categories based on an estimated amount of resistance or force of exertion and a combination of estimated rate of repetition (e.g., Viikari-Juntura et al. [1991b]; Kurppa et al. [1991]; Chiang et al. [1993]) or in terms of overall elbow stress [Dimberg 1987; Ritz 1995].

Studies Meeting the Four Evaluation Criteria

Of the studies examining epicondylitis and forceful exertion, three studies [Chiang et al. 1993; Luopajärvi et al. 1979; Moore and Garg 1994] fulfilled all four criteria. Most of these studies used combinations of risk factors in their analysis, of which forceful exertion was one.

Chiang et al. [1993] assessed exposure though observational methods, recording of tasks and biomechanical movements of representative workers. With these methods, they categorized fish processing workers into three exposure groups according to the ergonomic risks to the shoulders and upper limbs: (1) those with low force and low repetition (the comparison group), (2) those with high force or high repetition, and (3) those with both high force and high repetition. The diagnosis of epicondylitis included standard physical examination techniques of palpation and resisted extension and flexion of the elbow. Examination-defined cases were about one-half the number of cases defined by symptom alone. The analysis was stratified by gender, and those with metabolic diseases associated with MSDs were excluded. There was no significant difference in age between the comparison groups. Multivariate analysis was not carried out for the elbow in this study.

Luopajärvi et al. [1979] determined MSDs differences between female assembly line workers and shop assistants in a department store (cashiers were excluded from the comparison group). Exposure assessment involved on-site observation, video analysis and interviews. The assembly work was found to be repetitive, with up to 25,000 cycles per workday involving hand and finger motions. Specific cycles were not recorded for elbow motions; however, motions involving the hands and fingers involve tendons and muscles from the flexors and extensors that have their origin at the elbow. Static muscle loading of the forearm muscles, deviations of the wrist, and lifting were also found. The diagnosis of epicondylitis included standard physical examination techniques of palpation and resisted extension and flexion of the elbow. Subjects with previous trauma, arthritis, and other pathologies associated with MSDs were excluded. All participants were female. Covariates considered in the analysis included age, social background, hobbies, and the amount of housework performed. Duration of employment was not an issue because the factory had only been open a short time.

Moore and Garg [1994] carried out a medical records review using an epicondylitis case definition based on symptoms and physical examination and a semi-quantitative ergonomic assessment of 32 jobs at a meatpacking plant. The authors used their “Strain Index” to categorize jobs as “hazardous” or “safe” based on a number of factors: observation, video analysis, and judgements based on force, repetition, posture, and grasp. Force was estimated as percent of maximal strength by comparing the reported weight of the pertinent object with estimated average maximal strength of the worker for different types of pinches and grasps, then categorized into five levels.

These values were derived from population-based data stratified according to age, gender, and hand dominance. Repetition was recorded as cycle-time and exertions per minute. The exposure assessment in this study gave more weight to the factor of “force” than to repetition or posture (the force variable could increase to a higher categorization level if the job was repetitive, involved jerky motions, or extreme postures). Work histories, demographics, and pre-existing morbidity data were not collected on each participant. The diagnosis of epicondylitis extracted from the medical records included standard physical examination techniques of palpation and resisted extension and flexion of the elbow. Analyses were based on “full-time equivalents” for jobs, not individual workers. This analysis did not control for potential confounders; there was a slight preponderance of morbidity of all MSDs among females.

Studies Meeting at Least One Criteria

The Andersen and Gaardboe study [1993a], which did not carry out ergonomic assessment pertaining to the elbow, found a non-significant association between repetitive, forceful work and symptoms or physical findings consistent with epicondylitis. In the Andersen and Gaardboe study [1993a], the exposed group consisted of sewing machine operators.

Baron et al.’s [1991] measure of force was based on estimated assessment of exertion by experienced ergonomists through observation of tasks and video analysis, as well as weight of scanned items. Average forces for the grocery checkers were categorized as "low" and peak forces "medium" on a three-tiered scale ("low, medium, and high").

Byström et al.'s [1995] study of automobile assembly workers is reviewed in the Repetition section.

Dimberg's studies [1987] fulfilled three of the criteria but did not mention if examiners were blinded to exposure status. In the 1987 study, exposure was assessed by observational methods, jobs were categorized according to the amount of elbow stress in a particular job, but no individual measurements were made. Numerical results from the logistic regression model were not given in the paper, although employee category (blue collar versus white collar), gender, and degree of elbow stress were said not to be significant predictors of having any one of the three types of epicondylitis. The author classified epicondylitis into three types: leisure-related, no known cause, and work-related groups based on history. When the author specifically looked at "work-related" epicondylitis (criteria for such designation was not given) with respect to elbow stress, he found a significant trend with increasing levels of elbow stress.

The exposure assessment approach was different for the 1989 study by Dimberg et al. In the 1987 study by Dimberg, the exposure classification scheme was focused principally on the elbow and identified jobs with heavy elbow-straining work. In the 1989 study, the author focused on multiple health outcomes in the upper extremity and used an exposure classification scheme that was more broadly focused on the stress to the hand/wrist, elbow, and shoulder areas.

One study by Kurppa et al. [1991] was prospective. Here, workers in meat processing were categorized into strenuous and nonstrenuous jobs based on repetitive and forceful work. The strenuous tasks for the meatcutters consisted of cutting approximately 1,200 kg of veal or 3,000 kg of pork per day; the nonstrenuous tasks consisted primarily of office work. Workers had to have a physician visit and diagnosis in order to be considered a case—a restrictive definition requiring significant enough symptoms to seek out medical care.

Twenty-five percent of cases were diagnosed by physicians outside the plant, so examination techniques may not have been the same as those for the other 75%. The nonstrenuous group was similar to the strenuous group with regards to age, gender, and duration of employment, except for the small number of male sausage makers and male meatpackers—these were excluded from calculation of individual IRs.

Punnett et al.'s [1985] study of garment workers is reviewed in the Repetition section.

Ritz [1995] did not mention the participation rate in their study of welders and pipefitters but fulfilled the other three criteria. Workers studied were likely to be a representative sample, however, since all male employees who were taking their annual examinations during a three month period were enrolled in the study. The multiple logistic model analysis considered age and a variety of confounding factors. Among these public gas and water work employees, the welders and pipefitters who installed and repaired pipes were considered to have high exposure.

Roto and Kivi [1984] based their exposure on job title alone, but fulfilled the other three criteria. They compared meatcutters who had forceful, repetitive work to construction workers who had more varied tasks. The authors stratified the analysis by age and found the majority of cases in the older age groups. They also found that the meatcutters with epicondylitis had been exposed, on the average, five years longer than the other meatcutters. All the meatcutters had more than 15 years in their current occupation, which the authors attributed to support of the work-relatedness of the condition, although increasing age may have been a confounder or effect modifier.

Viikari-Juntura et al. [1991b] studied subjects at the same meat processing plant as Kurppa et al. [1991] using 3 cross-sectional examinations covering a period of 31 months. The same exposure assessment scheme used in the Kurppa et al. [1991] study mentioned above was used comparing workers in strenuous and nonstrenuous work. This study compared the prevalence of all cases of epicondylitis; cases due to injury or known non-occupational causes were not excluded. The diagnosis of epicondylitis included standard physical examination techniques of palpation and resisted extension and flexion of the elbow; the authors stated that palpation pressure increased on the second of the three cross-sectional examinations and may have influenced results. The investigators stated the comparison group was selected similar to the study group in gender, age, and duration of employment.

In conclusion, for the studies with less than our four criteria, four are supportive [Kurppa et al. 1991; Ritz 1995; Dimberg 1987; and Roto and Kivi 1984], two are non-supportive [Dimberg et al. 1989; Byström et al. 1995], and one is not very informative [Andersen and Gaardboe 1993a]. The results from the positive studies are unlikely to be due to confounding or selection bias. Overall, these studies provide limited support for the association of forceful repetitive work and epicondylitis.

Strength of Association—Force and Epicondylitis

Chiang et al. [1993] did not find an association between hand-intensive work (categorized based on forceful exertion and repetition) and epicondylitis when analyzing all workers at six fish processing plants. However, in examining the highest level of exposure (we calculated the odd ratios for men and women separately, which was not done in the article), we found a significant difference between males in the highest exposed group (Group III) and males in the lowest exposed group (Group I) (OR= 6.75) and a non-significant OR of 1.44 for women. Exposure in Group III was based on a combination of high-force exertion and high repetition; analysis of working techniques by gender was not performed, so the reason for the difference in the groups by gender is not known. The Chiang et al. [1993] study provides limited support for the association between high levels of forceful repetitive elbow work and epicondylitis.

Luopajärvi et al. [1979] found a non-significant difference overall in the prevalence of epicondylitis and pronator teres syndrome (3 versus 11 cases, OR 3.35 [95% confidence interval (CI) 0.86–19.1]); for lateral epicondylitis only, an OR of 2.73 (95% CI 0.66–15.94). There were five cases of medial epicondylitis in the assembly workers and none in the shop assistants. The increase in medial epicondylitis (an indeterminate OR because of "zero" cases in the shop assistants) was attributed to the difficult grasping movements involved in the assembly line work. They found that their female assembly workers tended to have physically light work, but this work required highly repetitive movements of the wrists and fingers and static muscle loading of the forearm muscles.

Using the Strain Index, Moore and Garg [1994] found a significant relationship between hazardous jobs (of which force was a major component) and upper extremity MSDs (of which epicondylitis was an important component). The results found a significant OR of 5.5 for a case of epicondylitis to occur in a hazardous job. When approximating the classification scheme for low and high force used by Silverstein et al. [1987] and then by Kurppa et al. [1991], Viikari-Juntura et al. [1991b], and Chiang et al. [1993], the association between forcefulness and the overall upper extremity morbidity in the study was again statistically significant (p<0.02).

The overall conclusion from the three studies that met our four criteria is that there is evidence for association between force and epicondylitis based on strength of association.

Strength of Association—Studies Not Meeting the Four Criteria: Force and Elbow MSDs

Baron et al. [1991] found an OR of 2.3 for the combination of factors, but this was not statistically significant. The authors mention that ergonomic analysis of the non-checkers showed that they also performed work requiring repetitive motions and awkward postures; therefore, the comparison probably resulted in a lower OR than had the referent group been truly unexposed to the ergonomic stressors.

Kurppa et al. [1991] found a strong significant relationship between strenuous jobs and epicondylitis (IR= 6.7), while Viikari-Juntura et al. [1991b] did not (OR=0.88, nonsignificant). These results may have been influenced by allowing "cases" who had recurrence in the same elbow to be counted as new cases (12 out of 57 employees with epicondylitis had more than one episode, and were counted twice). There was a median of 184 days between the episodes. In examining this study, it is important to see if the odds of having epicondylitis would be elevated if these workers with recurrences were only counted once. We recalculated the OR using only "persons" and not "single episodes of epicondylitis" in order to obtain a more conservative estimate. We counted, only once, the employees with recurrence, as well as the four employees mentioned with simultaneous occurrence in both elbows and subtracted these from the strenuous job cases. This gave a total of 44 cases of epicondylitis among the strenuous group.

Using this estimate, more restrictive than that found in the article, gives an OR of 5.5 (2.4, 12.7) for epicondylitis among the workers with strenuous jobs versus those with nonstrenuous jobs. The Kurppa et al. [1991] prospective study also found the IR of epicondylitis in nonstrenuous jobs to be similar to Allender's [1974] population background prevalence rate (1%) for epicondylitis.

Ritz [1995] found a significant OR for 10 years of high exposure to elbow straining work: 1.7 for currently held jobs and 2.2 for formerly held jobs. The significant OR for moderate exposure in the current job was 1.4 for 10 years of exposure. This study provides support for the association of forceful work with epicondylitis.

We calculated odd ratios from data in Dimberg's [1987] study and found an OR for moderate stress versus none or light elbow stress of 2.9, and for heavy versus none or light stress of 7.4. Heavy stress in the elbows was assigned to job titles like blaster, driller, or grinder. The major limitation of this analysis of the work-related cases is that it did not consider age, a likely confounder. Overall, this study provides support for the association between forceful work and epicondylitis, particularly in older workers.

The 1989 Dimberg et al. study was not supportive of an association between lateral epicondylitis and forceful repetitive work, but was positive for "mental stress at work" at the onset of symptoms for lateral epicondylitis (p<0.001). As a result of the specific elbow exposure assessment, we believe that with regards to stressful or

forceful elbow exertions that the 1987 study is more informative.

The study conducted by Roto and Kivi [1984] found an OR of 6.4 (95% CI 0.99–40.9) using an exposure assessment based on job title alone (meatcutters were assumed to have more forceful jobs than construction workers). Only one referent had epicondylitis.

In the paper by Viikari-Juntura et al. [1991b], the cases of epicondylitis not listed as insidious all involved forceful, repetitive tasks (although some of these tasks were not related to work). Prevalences of "epicondylar pain" and "sick leave due to epicondylar pain" were significantly different between the two groups (OR 1.9 and 2.1). There was no significant difference in the prevalence of epicondylitis (combined work and non-work related) between workers in strenuous versus nonstrenuous jobs (OR=0.88). In 95 women sausage makers, there were four cases with insidious onset, while among 160 women referents there were two cases, one with insidious onset, the other related to an "exceptional task of cutting cheese." The resulting OR was 6.9 (95% CI 0.74–171). This study also found that rates of "epicondylar pain" and "sick leave due to epicondylar pain" differed significantly between the two groups (OR 1.9 and 2.1, respectively). Rates of medically diagnosed cases of epicondylitis were not statistically different between the two groups, but the results for epicondylar pain (causing sick leave in the two groups), and the fact that the majority of cases in both groups were due to events involving strenuous, repetitive tasks, give some support to forceful, repetitive work as
a cause.

Byström et al. [1995] noted that the low frequency could not be attributed to selected subjects being absent, as all persons on leave participated in the investigation. The authors also stated that "exposure to repetitiveness and force in automobile assembly line work may be less than in other investigated work situations." Because the authors did not give quantitative or qualitative information on the forcefulness or repetitiveness of jobs included in the study group, it is difficult to know whether these jobs were appropriate to use to study epicondylitis.

Temporal Relationship: Force and Epicondylitis

See temporal relationship above in Repetition and Epicondylitis.

Consistency of Association

The studies that met the four criteria were fairly consistent in their strength of association between force and epicondylitis, with most ORs between 2.5 and 7.0. Focusing on those studies that compared workers exposed to force that was documented to be at a high level, to those exposed to a low level, all studies [Chiang et al. 1993; Kurppa et al. 1991; Moore and Garg 1994] were consistent.

Of those 10 studies that examined force but did not fulfill the four criteria, two studies had a significant OR greater than 3.0, three studies had significant ORs between 1.0 and 3.0, one had a nonsignificant OR between 1.0 and 3.0, and two had an OR less than 1.0. Two had statistically significant findings but did not report ORs. Most of these studies examined workers in repetitive, forceful job tasks and did not separate out

the independent effect of repetition through any analytic method.

Viikari-Juntura et al.'s [1991b] study did not exclude workers with elbow symptoms or physical findings that were due to acute injury not related to the job, which may account for the contrasting result. In fact, in that study, four workers with acute non-work-related epicondylitis in the nonstrenuous group were noted in the journal article. Another consideration for inconsistency is due to grouping of studies, which may all fulfill good epidemiologic criteria, may all examine the same risk factor, but may compare groups that do not have similar contrasting levels of exposure. For example, the Chiang et al. [1993] study found statistically significant results in men when comparing high force/high repetition jobs to low force/low repetition jobs. Baron et al. [1991], on the other hand, compared checkers in low force, medium repetition jobs to noncheckers in low force, low repetition jobs.

Two factors explain the difficulty in determining the reasons for the apparent inconsistencies among the studies on forceful and repetitive work. First, very few of the exposure assessments were quantitative—this is due to existing limitations in directly measuring exposure in detail in most field studies. As a result, there is likely to be frequent non-differential misclassification of exposure. Second, most of the studies completed have been cross-sectional, and therefore subject to survivor bias.

As an example, Chiang et al. [1993] found that epicondylitis was significantly associated with increasing repetitiveness and

forcefulness among fish processors employed less than 12 months. For those working for 12 to 60 months, a similar trend was found, but a reverse trend was found in those workers employed for over 60 months. The authors stated that because most of the workers were semi-skilled, they were likely to leave their job if they felt frequent muscle pain because of it. They went further to say that the selection mechanism may explain the lack of significant associations between the disorders and the duration of employment. There was no indication that the authors pursued this hypothesis by trying to identify former workers who may have left. Turnover rate was not discussed. This example highlights two important factors concerning the cross-sectional studies examining work-related epicondylitis: there is some evidence that older workers may be at higher risk of epicondylitis [Dimberg 1987; Ritz 1995], and there is also a "survivor" effect, which results in the loss to the study of affected workers. These two factors make the interpretation of duration of disease relationships complex and may affect the estimate of the risk of disease.

There were studies that used more accurate exposure assessment or had comparison groups with marked differences in levels of exposure to forceful and repetitive work that were positive, such as the Kurppa et al. [1991] study of meatcutters, sausage makers, and packers, Moore and Garg's [1994] study of pork processors; Dimberg's [1987] study of blasters, drillers, grinders, and others in an engineering industry; Ritz's [1995] study of pipefitters and welders in a public utility; and Roto and Kivi's [1984] study of meatcutters. There were studies with these characteristics that were negative, such as the Viikari-Juntura et al. [1991b] study of meatcutters, sausage makers, and packers; and the study by Dimberg et al. [1989] of blue- and white-collar workers in the automobile industry. In both of these studies, those cases of epicondylitis listed in the comparison groups were due to highly repetitive, forceful activities. The lack of a significant difference in the prevalence of the disorder between the two groups may be because the referent, "low" exposure groups had a higher incidence of non-work-related lateral epicondylitis.

Coherence of Evidence

The epidemiologic results of finding the majority of cases occurring in highly repetitive, forceful work [Moore and Garg 1994; Chiang et al. 1993; Kurppa et al. 1991; Kopf et al.1988] are consistent with the evidence from biomechanical and physiologic findings, as well as from sports medicine literature and older medical clinical case series. In cases of lateral epicondylitis occurring in workplaces as well as in sports, the forearm extensors are repetitively contracted and produce a force that is transmitted via the muscles to their origin on the lateral epicondyle. These repetitive contractions produce chronic overload of the bone-tendon junction, which in turn leads to changes at this junction. The most common hypothesis is that microruptures occur at the attachment of the muscle to bone (usually at the origin of the extensor carpi radialis brevis muscle), which causes inflammation. Peƒina et al. [1991] did not agree with the microrupture theory; they theorized that overuse leads to avascularization of the affected muscle origin, which leads to overstimulation of the free nerve endings and results in aseptic inflammation. Further repetition of the offending movements causes angiofibroblastic hyperplasia of the origin. Nirschl [1975] stated that the degree of angiofibroblastic hyperplasia is correlated to the duration and severity of symptoms. On histologic analysis of severe cases of epicondylitis, one can see the characteristic invasion of fibroblasts and vascular tissue, the typical picture of angiofibroblastic hyperplasia.

Prior to many of the epidemiologic studies, there were numerous reports in the medical literature of clinical case series that suggest a relationship between epicondylitis and repetitive, forceful work. For example, as early as 1936 Cyriax reported that with regard to patients with lateral epicondylitis, "those patients who remember no special overexertion will be found to be working at screwing, lifting, hammering, ironing, etc., or to be violinists, surgeons, masseurs, etc." Cyriax had designated a "Chronic Occupational" variety of tennis elbow, in which he stated that "often no history of an injury is obtainable, but the patient's occupation at once provides the clue." He cited "work which entails repeated pronation and supination movements with elbow almost fully extended" to be responsible for epicondylitis [Cyriax 1936]. Feldman et al. [1987] reported that occupations with work tasks requiring repeated pronation and internal/external rotation of the forearm are at high risk of pronator teres syndrome (compression of the median nerve as it courses through the pronator teres muscle in the forearm). A number of case series have reported similar findings [Hartz et al. 1981; Morris and Peters 1976].

Sinclair [1965] reported 2 case series of patients with tennis elbow (lateral epicondylitis), 44 patients treated between 1959-1961 and 38 patients treated between 1961-1963. In the first group of 267, the 130 (48%) whose onset occurred spontaneously had occupations that included gripping tools with consequent forearm extensor muscle contraction and repetitive supination/ pronation of the forearm. In the second group of 26, the 23 (88%) who had spontaneous onset worked in jobs with constant gripping or repetitive movements.

Many case studies of professional athletes have documented that forceful, repeated dorsiflexion, pronation, and supination movements with the elbow extended can cause epicondylitis. [Ollivierre et al. 1995; Priest et al. 1977; King et al. 1969]. Most cases have occurred in baseball pitchers and tennis players. Occupations involving movements described above have also been found to have increases in rates of elbow MSDs. This literature has also referred to increased occurrence in occupations requiring force, awkward postures, and repetitive use of the elbow and forearm [Lapidus and Guidotti 1970; Mintz and Fraga 1973; Berkeley 1985]. These reports, though mainly case series, have lead to further studies that examined the links between exposure and epicondylitis.

An example of an early occupational study is one by Mintz and Fraga [1973], who found that foundry workers (with an average of 14 years of employment) who used tongs requiring twisting and bending of the elbows/forearms for eight hours per day had decreased elbow flexion and extension and pain on physical examination, as well as severe radiographically documented osteoarthritis localized to the elbows. In the studies that are reviewed in Tables 4-1 through 4-4, the occupations with the highest rates of epicondylitis, such as drillers, packers, meatcutters, and pipefitters, are consistent with the force-repetition model of the causation of epicondylitis. The development of epicondylitis in these workers is consistent with proposed biological mechanisms and is plausible.

The lack of elbow MSDs and work factors in some of the studies with occupations like sewing workers [McCormack et al. 1990] or automobile assembly line workers [Byström et al. 1995], most likely reflects the interplay of two factors. The movement of affected workers out of high exposure jobs limits the ability of cross-sectional studies to accurately determine associations between work factors and epicondylitis. Our ability to accurately identify working conditions with an elevated risk for epicondylitis may require an exposure assessment of each job to a degree that has been beyond the limits of current epidemiological methods. As a result, misclassification of exposure may be common. Overall, the majority of the epidemiologic studies are supportive of the hypothesis of an increase risk of epicondylitis for occupations that involve forceful and repetitive work, frequent extension, flexion, supination, and pronation of the hand and the forearm. The surveillance data are also supportive of this hypothesis [Roto and Kivi 1984; Washington State Department of Labor and Industry 1996]. The highest relative risks for epicondylitis in Finland were with mechanics, butchers, food industry workers,
and packers; the highest industries in Washington State for 1987-1995 [Silverstein et al. *In Press*] were construction workers, meat dealers, and foundry workers—all occupations with repetitive, forceful work involving the arms and hands and requiring pronation and supination.

Evidence of a Dose-Response

Relationship for Force

The Baron et al. [1991] study is mentioned above in the Repetition Section as showing a dose-response relationship for number of hours of work per week. Chiang et al. [1993] found that among men the prevalence of epicondylitis increased with increasing force and repetition in fish processors. In several studies, only dichotomous divisions were made, so conclusions concerning an exposure-response relationship cannot be drawn. However, we can see significantly contrasting rates of elbow MSDs between high- and low-exposure groups. Moore and Garg [1994] found a higher risk in workers with high-strain jobs compared to those with low-strain jobs. Kurppa et al. [1991] found higher risk in workers with strenuous jobs compared to those with nonstrenuous jobs, and that female sausage makers had an increase in epicondylar tenderness with increasing duration of employment. While Dimberg [1987] found no difference in epicondylitis between blue- and white-collar workers, he found that workers with elbow pain severe enough to require a physician consult were significantly more often in those jobs identified independently as having high elbow stress. Dimberg also found a statistically significant correlation coefficient for lateral epicondylitis and time spent in the present job. Luopajärvi et al. [1979] found a higher rate of epicondylitis and pronator teres syndromes in a
high-exposure group of assembly line packers compared to the referent group of shop assistants. Overall, these studies provide considerable evidence for a difference in level of risk for epicondylitis when there are marked differences in the level of exposure to forceful and repetitive tasks.

Ritz [1995] reported a positive dose-response relationship between duration of exposure to gas and waterworks jobs regarded as moderately and highly stressful to the elbow and epicondylitis. Roto and Kivi [1984] reported that all workers with epicondylitis in their meat-packing facility worked for more than 15 years in the strenuous job category and had been exposed an average of 5 years longer than non-diseased workers. Kopf et al. [1988] reported that in their study of brick layers, with increasing levels of job demands (defined as either heavy physical work, awkward working postures, repetitive movements, or restriction in standing position), the OR increased from 1.8 to 3.4. These studies, with less clear contrasts in exposure, provide support for the exposure-response relationship between epicondylitis and forceful, repetitive work.

POSTURE

Definition of Postures for Elbow MSDs

We chose to include those studies that addressed posture or examined workers in those activities or occupations that require repeated pronation and supination, flexion/extension of the wrist, either singly or in combination with extension and flexion of the elbow.

Studies Reporting on the Association of Posture and Epicondylitis

The six studies in Table 4-3 addressed posture variables. Of these, only the studies by Moore and Garg [1994] and Luopajärvi et al. [1979] fulfilled all four criteria. The details of these studies are discussed in the Repetition and Force sections.

Strength of Association—Posture and Epicondylitis

Studies Meeting the Four Evaluation Criteria

The Moore and Garg [1994] study (also discussed above) recorded wrist posture using a classification similar to Armstrong et al. [1982] and Stetson et al. [1991]. Pinch grasp was also noted to be present or absent. In this study, posture was not found to be significantly associated with "hazardous" jobs. This may be due to the heavier weighting given the force rating system than the posture or repetition scale. For example, if a job required extreme posture, the authors increased the force rating instead of the posture rating. If a combination of extreme posture and high-speed movement was required, then the force rating was raised by two levels, but not the posture rating. Data that would allow analysis of the incidence of epicondylitis and the exposure to extreme posture were not presented.

Luopajärvi et al.'s [1979] assessment was focused on the extreme work position of the hands but not the elbow; it included extension, flexion and deviation of the wrists. Although there was a non-significant association between assembly line work and the presence of either epicondylitis or pronator teres syndrome in shop assistants (11 cases versus 3), there were 5 cases of medial epicondylitis and 2 cases of pronator teres syndrome in the assembly workers and none in the shop assistants. The greater prevalence of medial epicondylitis in assembly workers was attributed to the difficult grasping movements involved in the assembly line work. The authors stated that the overall prevalence may have been "connected with the constant overstrain of flexors in work."

Studies Not Meeting the Four Evaluation Criteria

The Dimberg [1987] study stated that over-exertion of the extensor muscles of the wrist due to gripping and twisting movements prior to the onset of symptoms was verified in 28 of the 40 (70%) of the cases, of which 14 were considered to be caused by work. In the study by Dimberg et al. [1989], the guidelines for classification include repeated rotation of the forearms and wrists in Group 1, large and frequent rotations in extreme positions in Group 2, but fail to include work involving frequent rotations in the highest exposed group, Group 3. The difference in exposure classification scheme may explain why there was no relationship between prevalence of epicondylitis and increasing work strain.

Hughes and Silverstein [1997] found a strong, statistically significant association (OR 37) between elbow/forearm disorders and "the number of years of forearm twisting" in their study of aluminum workers. However, this study had an overall low participation rate (55%), which limits the interpretation of its result.

The other study that may be interpreted as related to a posture variable is the one by Hoekstra et al. [1994]. This study evaluated video display terminal users at two work sites differing only in whether adjustable office equipment was present. By self-reported symptoms and exposure observations, the Hoekstra et al. [1994] study found that having a "non-optimally adjusted" chair was associated with elbow MSDs. This improper chair adjustment was thought to increase shoulder and elbow flexion, as well as wrist deviation, thus producing more symptoms. These conclusions should be considered to be hypothesis generating and not definitive.

Temporal Relationship

There are no prospective studies that address posture and epicondylitis. The one prospective study concerning epicondylitis did not address posture.

Consistency in Association

There are too few occupational epidemiologic studies that address posture and epicondylitis to meaningfully discuss consistency of association.

Coherence of Evidence

Please refer to the "Repetition Section and Coherence of Evidence" for a discussion of the sports literature, and the combination of factors, including extreme postures that have been documented concerning epicondylitis.

Exposure-Response Relationship

There is little evidence on which to base a discussion exposure response relationship in the epidemiologic studies. Once again, the reader is referred to the biomechanical sports literature.

EPICONDYLITIS AND THE ROLE OF CONFOUNDERS

The model for epicondylitis clearly implies that both occupational and non-occupational activities can cause the disorder. Several studies [Ritz 1995; Andersen and Gaardboe 1993a; Dimberg 1987] directly address the issue of work-related versus non-work-related exposures by assessing both. Two of the most important potential confounders or effect modifiers are age and duration of employment. In Dimberg's [1987] and Ritz's [1995] studies, older workers had high rates of epicondylitis. Nevertheless, in both studies the increase in the risk for epicondylitis in the high-exposure group does not seem related primarily to age, independent of intensity and duration of exposure. Furthermore, the incidence of elbow MSDs unlike most MSDs, has been found to decrease after retirement age, after peaking during the fourth and fifth decades.

Many of the studies controlled for several possible confounders in their analyses. In general, for epicondylitis, psychosocial factors or gender do not appear to be important confounders in occupational studies.

CONCLUSIONS

The epidemiologic studies reviewed in this section focused principally on the risk of epicondylitis in workers performing repetitive job tasks requiring forceful movements. These forceful movements included, but were not limited to, repeated dorsiflexion, flexion, pronation, and supination, sometimes with the arm extended. Clinical case series of occupationally-related epicondylitis and studies of epicondylitis among athletes had suggested that repeated forceful dorsiflexion, flexion, pronation, and supination, especially with the arm extended, increased the risk of epicondylitis. In general, the epidemiologic studies have not quantitatively measured the fraction of forceful hand motions most likely to contribute to epicondylitis; rather, they have used as a surrogate qualitative estimation the presence or absence of these types of hand movements [Viikari-Juntura et al. 1991b]. Although we recognize this limitation of the epidemiologic studies, there is value in assessing where we are in regards to the epidemiologic evidence of causal inference.

There is epidemiologic evidence for the relationship between forceful work and epicondylitis. Those studies that base their exposure assessment on quantitative or semiquantitative data have shown a solid relationship. We conclude that there is insufficient evidence for the association of repetitive work and epicondylitis. For extreme posture in the workplace, the epidemiologic evidence thus far is also insufficient, and we turn to the sports medicine literature to assist us in evaluating the risk of the single factors of repetition and posture. The strongest evidence by far when examining the relationship between work factors and epicondylitis is the combination of factors, especially at higher levels of exposure. This is consistent with the evidence that is found in the biomechanical and sports literature.

Most of the relevant occupational studies were cross-sectional; the current estimates of the level of exposure were used to estimate past and current exposure. Despite the cross-sectional nature of the studies, it is likely, in our opinion, that the exposures predated the onset of disorders in most cases.

When we examine all of the studies, a majority of studies are positive. The association between forceful and repetitive work involving dorsiflexion, flexion, supination, and pronation of the hand is definitely biologically plausible. These motions can cause the contraction of the muscle-tendon units that attach in the area of the medial and lateral epicondyles of the elbow.

The evidence for a qualitative exposure-response relationship overall was considerable for the combination of exposures, with studies examining differences in levels of exposure for the elbow, and corresponding evidence for greater risk in the highly exposed group. In contrast, we found one study with clear differences in exposure and no evidence of an increase in risk [Viikari-Juntura et al. 1991b].

In summary, the combination of the biological plausibility, the studies with more quantitative evaluation of exposure factors finding strong associations, and the considerable evidence for the occurrence with combinations of factors at higher levels of exposure provide evidence for the association between repetitive, forceful work and epicondylitis. There are several important qualifications to this conclusion. Forceful and repetitive work is most likely a surrogate for repetitive, forceful hand motions that cause contractions of the muscles whose tendons insert in the area of the lateral and medial epicondyles of the elbow. While the studies do not identify the number or intensity of forceful contractions needed to increase the risk of epicondylitis, the levels are likely to be substantial. Future studies should focus on the types of forceful and repetitive hand motions such as forceful dorsiflexion, pronation, and supination that result in forceful contractions of the muscle tendon units that insert in the area of the lateral and medial epicondyles. Common non-occupational activities, such as sport activities, which cause epicondylitis should be considered. Older workers may be at some increased risk. Finally, even though the epidemiologic literature shows that many affected workers continue to work with definite symptoms and physical findings of epicondylitis, survivor bias should be addressed.

Table 4-1. Epidemiologic criteria used to examine studies of elbow MSDs associated with repetition

Study (first author and year)	Risk indicator (OR, PRR, IR or *p*-value)*,†	Participation rate ≥70%	Physical examination	Investigator blinded to case and/or exposure status	Basis for assessing elbow exposure to repetition
Met at least one criterion:					
Andersen 1993a	1.7	Yes	No	Yes	Job titles or self-reports
Baron 1991	2.3	No	Yes	Yes	Observation or measurements
Burt 1990	2.8[†]	Yes	No	Yes	Job titles or self-reports
Byström 1995	0.74	Yes	Yes	No	Job titles or self-reports
McCormack 1990	0.5–1.2	Yes	Yes	NR[‡]	Job titles or self-reports
Met none of the criteria:					
Ohlsson 1989	1.5–2.8	NR	No	NR	Job titles or self-reports
Punnett 1985	2.4[†]	No	No	NR	Job titles or self-reports

[*]Some risk indicators are based on a combination of risk factors—not on repetition alone (i.e., repetition plus force, posture, or vibration). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

[†]Indicates statistical significance.

[‡]Not reported.

Figure 4-1. **Risk Indicator for "Repetition" and Elbow Musculoskeletal Disorders**

(Odds Ratios and Confidence Intervals)

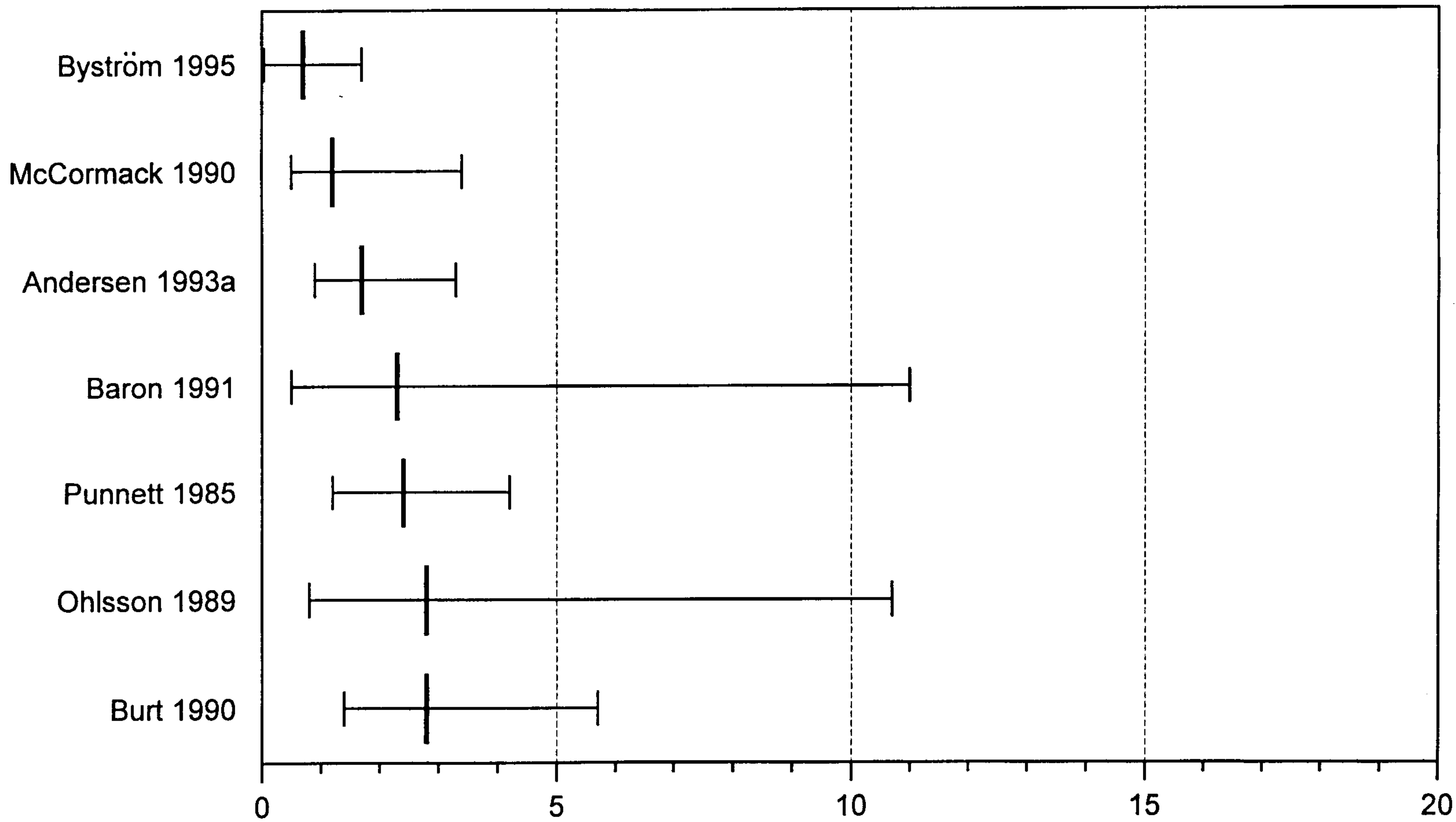


Table 4-2. Epidemiologic criteria used to examine studies of elbow MSDs associated with force

Study (first author and year)	Risk indicator (OR, PRR, IR or *p*-value)[*,†]	Participation rate $70%	Physical examination	Investigator blinded to case and/or exposure status	Basis for assessing elbow exposure to force
Met all four criteria:					
Chiang 1993	6.75[†] (males) 1.44 (females)	Yes	Yes	Yes	Observation or measurements
Luopajärvi 1979	2.7	Yes	Yes	Yes	Observation or measurements
Moore 1994	5.5[†]	Yes	Yes	Yes	Observation or measurements
Met at least one criterion:					
Andersen 1993a	1.7	Yes	No	Yes	Job titles or self-reports
Baron 1991	2.3	No	Yes	Yes	Observation or measurements
Byström 1995	0.74	Yes	Yes	No	Job titles or self-reports
Dimberg 1987	NR[†,‡]	Yes	Yes	NR	Observation or measurements
Dimberg 1989	NR	Yes	Yes	NR	Observation or measurements
Kurppa 1991	6.7[†]	Yes	Yes	NR	Observation or measurements
Punnett 1985	2.4[†]	Yes	No	NR	Job titles or self-reports
Ritz 1995	1.4–1.7[†]	NR	Yes	Yes	Observation or measurements
Roto 1984	6.4[†]	Yes	Yes	Yes	Job titles or self-reports
Viikari-Juntura 1991b	0.88	Yes	Yes	NR	Observation or measurements

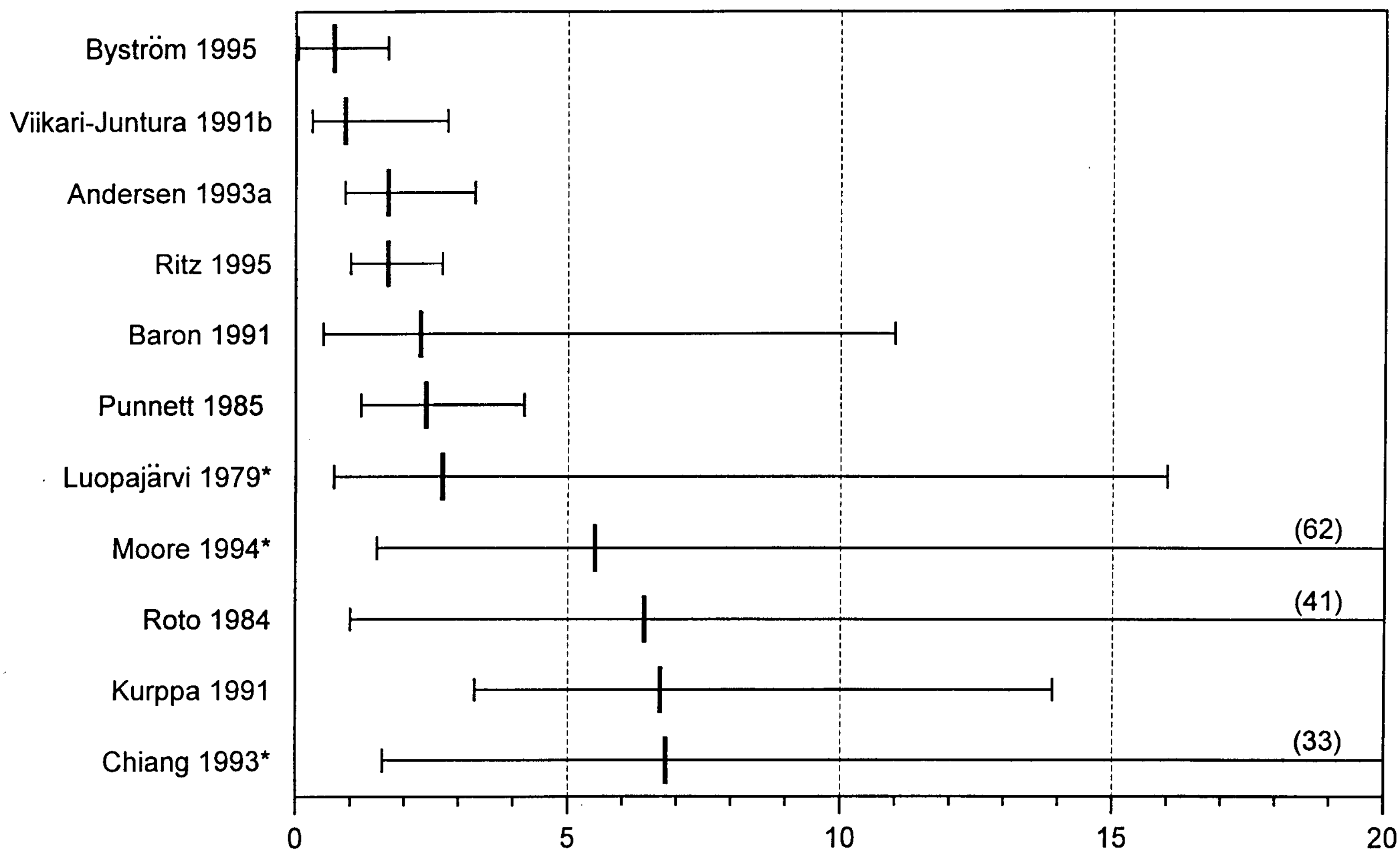
[*]Some risk indicators are based on a combination of risk factors—not on force alone (i.e., force plus repetition, posture, or vibration). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

[†]Indicates statistical significance. If combined with NR, a significant association was reported without a numerical value.

[‡]Not reported.

Figure 4-2. **Risk Indicator for "Force" and Elbow Musculoskeletal Disorders**

(Odds Ratios and Confidence Intervals)



* Studies which met all four criteria.
Note: Two studies indicated statistically significant associations without reporting odds ratios. See Table 4-2.

Table 4-3. Epidemiologic criteria used to examine studies of elbow MSDs associated with posture

Study (first author and year)	Risk indicator (OR, PRR, IR or *p*-value)[*,†]	Participation rate $70%	Physical examination or medical records	Investigator blinded to case and/or exposure status	Basis for assessing elbow exposure to posture
Met all four criteria:					
Luopajärvi 1979	2.7	Yes	Yes	Yes	Observation or measurements
Moore 1994	NR[‡]	Yes	Yes	Yes	Observation or measurements
Met at least one criterion:					
Dimberg 1987	NR[†]	Yes	Yes	NR	Observation or measurements
Dimberg 1989	NR	Yes	Yes	NR	Observation or measurements
Hoekstra 1994	4.0[†]	Yes	No	Yes	Job titles or self-reports
Hughes 1997	37.0[†]	No	Yes	NR	Observation or measurements

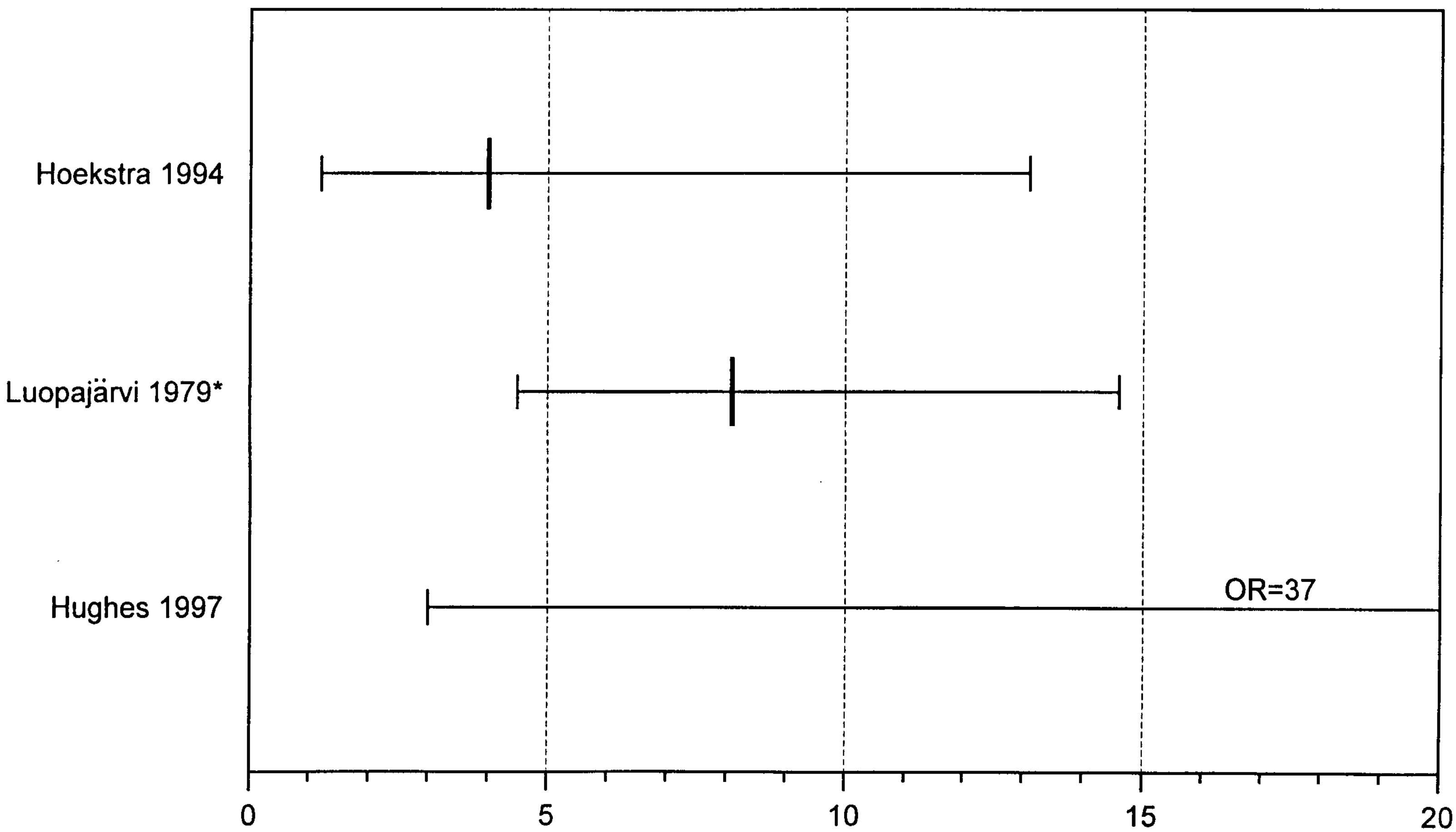
[*]Some risk indicators are based on a combination of risk indicators—not on posture alone (e.g., posture plus repetition, force, or vibration). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

[†]Indicates statistical significance. If combined with NR, a significant association was reported without a numerical value.

[‡]Not reported.

Figure 4-3. **Risk Indicator for "Posture" and Elbow Musculoskeletal Disorders**

(Odds Ratios and Confidence Intervals)



* Studies which met all four criteria.

Note: Some studies indicate a statistical significant association without a risk indicator. See Table 4-1.

Table 4-4. Epidemiologic criteria used to examine studies of elbow MSDs associated with vibration

Study (first author and year)	Risk indicator (OR, PRR, IR or *p*-value)[*,†]	Participation rate ≥70%	Physical examination or medical records	Investigator blinded to case and/or exposure status	Basis of assessing elbow exposure to vibration
Met at least one criterion:					
Bovenzi 1991	4.9[†]	NR[‡]	Yes	Yes	Observation or measurements

[*]Some risk indicators are based on a combination of risk indicators—not on vibration alone (e.g., vibration plus repetition, force, or posture). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

[†] Indicates statistical significance.

[‡] Not reported.

Table 4–5. Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Andersen and Gaardboe 1993a	Cross-sectional	424 female sewing machine operators, compared to 781 females from the general population of the region and an internal referent group of 89 females from the garment industry.	Outcome: Questionnaire: continuous pain lasting > 1 month since starting career; pain for > 30 days. Exposure: Job categorization based on "authors' experiences" as occupational health physicians and involved crude assessment of exposure level and exposure repetitiveness. Jobs involving high repetitiveness (several times/min) and low or high force, and jobs with medium repetitiveness (many times/hr) combined with high force were classified as high exposed jobs; jobs with medium repetitiveness and low force and jobs with more variation and high force were classified as medium exposed. Job titles such as teachers, self-employed, trained nurses, and the academic professions were "low exposed." Exposure also measured as years as sewing machine operator.	4.5%	2.6%	1.7	0.9-3.3	Participation rate: 78.2%. Examiners blinded to control/subject status. Adjusted for age, number of children, exercising, smoking, socioeconomic status.

(Continued)

Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Baron et al. 1991	Cross-sectional; case-referent	Grocery checkers using laser scanners (n=124, 119 females, 5 males) compared to other grocery store workers (n=157, 56 females, 101 males); excluded 18 workers in meat, fish, and deli departments, workers under 18, and pregnant workers.	Outcome: Self-administered questionnaire and physical exam. Case defined as the presence of pain, numbness, tingling, aching, stiffness or burning in the elbow region as previous non-occupational injury; symptoms must have begun after employment at the supermarket of employment and in the current job, and last >1 week or occurred once a month within the past year. Physical Exam: Tenderness at the lateral/medial epicondyle and pain with palpation and resisted motion. Exposure: Based on job category, estimates of repetitiveness, average and peak forces based on observed and videotaped postures, weight of scanned items, and subjective assessment of exertion. The majority of cashiers were categorized as having "medium" levels of repetition for the hand (defined in this study as making 1250 to 2500 hand movements/hr).	8% among checkers	õ	2.3	0.5-11	Participation rate: 85% checkers; 55% non-checkers in field study. Following telephone survey 91% checkers and 85% non-checkers. Examiners blinded to worker's job and health status. Age, hobbies, second jobs, systemic disease and height were considered as covariates in the multivariate analyses. Total repetitions/hr ranged from 1,432 to 1,782 for right hand and 882 to 1,260 for left hand. Average forces were low and peak forces medium. No statistical significance associated between duration of employment as a checker and elbow MSDs. Multiple awkward postures of all upper extremities recorded but not analyzed in models. Statistically significant increase in elbow MSD with increase in hr/week "checking."

(Continued)

Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Bovenzi et al. 1991	Cross-sectional	Vibration-exposed forestry operators using chain-saws (n=65) and maintenance workers (n=31, control group).	Outcome: Epicondylitis syndrome: Pain at the epicondyle either during rest or motion, local tenderness at the lateral or medial epicondyle; pain during resisted flexion/extension of the fingers and wrist with the elbow flexed, palpated local tenderness at the lateral/medial epicondyle. Exposure: Direct observation of awkward postures, manual forces and repetitiveness evaluated via checklist. Vibration measured from two chain saws.	29.3	6.4%	For vibration exposed group >7.5 m/s^2: OR=4.9 (adjusted) OR=5.99 (unadjusted)	1.27-56	Participation rate: Not reported. Analysis controlled for age and ponderal index. Controls found to have several risk factors for MSDs at work-static arm and hand overload, overhead work, stressful postures, non-vibrating hand tool use. Controls actually had a greater proportion of the time in work cycles shorter than 30 sec than forestry workers.

(Continued)

Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	95% CI	Comments
Burt et al. 1990	Cross-sectional	Newspaper employees (n=836, females=55%). Workers fulfilling case definitions compared to those who did not fulfill case definition.	Outcome: Self administered questionnaire. Case defined as the presence of pain, numbness, tingling, aching, stiffness, or burning in the elbow region as previous non-occupational injury. Symptoms began after starting the job, last > 1 week or occurred once a month within the past year; reported as "moderate" (3) or greater on a 5-point scale. Exposure: Based on observation of job tasks, then categorized by job title. A separate job analysis using a checklist and observational techniques was carried out for validating questionnaire exposure data.	Male: 11% Female: 14%	ð	80% to 100% time typing compared to 0% to 19%: OR=2.8 Reporters compared to others: OR=2.5	1.4-5.7 1.5-4.0	Participation rate: 81%. Analysis controlled for age, gender, years on the job. Psychosocial factors dealing with job control and job satisfaction were addressed in questionnaire. Job analysis found significant correlation (0.56) between reported average typing time/day and observed 8 hr period of typing ($p < 0.0001$). Reporters were characterized by high, periodic demands (deadlines), although they had high control and high job satisfaction. Number of workers in some non- typing jobs not reported. Case definition based on symptoms alone.

(Continued)

Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Byström et al. 1995	Cross-sectional	Automobile assembly line workers (n=199) compared to a randomly selected group from the general population (n=186). The automobile assembly line workers were randomly selected from a primary group of 700 assembly line workers. These original 700 workers had been randomly selected from the 2,334 assembly workers of a Swedish automobile factory.	Outcome: Epicondylitis was defined as tenderness to palpation of the lateral or medial epicondyle and pain at the same epicondyle or in the forearm extensors or flexors on resisted wrist extension or flexion. Exposure: No evaluation of repetition, force, posture, or vibration occurred in this study to evaluate risk factors for epicondylitis. "Assembly line worker" vs. "Population referent" was used. Hand grip strength was evaluated. Forearm muscular load and wrist angle were evaluated for a subgroup in this population but were not used in this analysis [Hägg et al 1996].	Tender lateral epicondyle: 4.3% Epicondy-litis: 0 cases	Tender lateral epicondyle: 12.4% Epicondy-litis: 1%	PRR for tender lateral epicondyle: 0.74	0.04-1.7	Participation rate: 96%. Comparison group is from the MUSIC study (Hagberg and Hogstedt, 1991). Examiners were blinded to questionnaire responses but not exposure status. Analysis stratified by gender and age <40 years. Psychosocial variables and other potential confounders or effect modifiers were addressed by Fransson-Hall et al. [1995]. Pain-pressure threshold (PTT) was evaluated. PTT was not related to age. It was higher among women with short employment compared to those who had been employed for a long time. No correlation was found between low MCV and subjective or objective signs.

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Chiang et al. 1993	Cross-sectional	207 fish processing workers, 67 males and 140 females, divided in 3 groups: (I) low force, low repetition (comparison group, n=61); (II) high force or high repetition (n=118); (III) high force and high repetition (n=28).	Outcome: Prevalence of lateral or medial epicondylitis (local tenderness, pain in resisted extension or flexion of the wrist and fingers, decreased hand grip strength compared to the opposite hand). Exposure: Assessed by observation and recording of tasks and biomechanical movements of three workers, each representing one of 3 study groups. Highly repetitive jobs with cycle time <30 sec or >50% of cycle-time performing the same fundamental cycles. Hand force from EMG recordings of forearm flexor muscles. Classification of workers into 3 groups according to the ergonomic risks of the shoulders and upper limbs: Group I: low rep. and low force; Group II: high repetition or high force; Group III: high repetition and high force.	Group II: 15% Male: 10%; Female: 17% Group III: 21% Male: 33%; Female: 18% Physician observed epicondy-litis, all cases: 14.5 %	Group I: 10% Male: 6%; Female: 14%	Crude ORs calculated from data presented: Group II vs. Group I, males: OR=1.7 Group II vs. Group I, females: OR=1.2 Group III vs. Group I, males: OR=6.75 Group III vs. Group I, females: OR=1.44	0.3-9.2 0.4-3.4 1.6-32.7 0.3-5.6	Participation rate: Authors reported: "In order to prvent selective bias all employees in the fatories were observed initially." Workers examined in random sequence to prevent observer bias, examiners blinded to case status. Analysis stratified by gender. No significant age difference in exposure groups. Logistic regression not performed for epicondylitis because of lack of significant trend with increasing exposure. Workers with hypertension, diabetes, history of traumatic injuries to upper limbs, arthritis, or collagen diseases excluded from study group. Physician observed cases had about ½ the prevalence of symptoms of elbow pain (9.8 vs. 18.0; 5.3 vs. 19.5; 35.7 vs. 17.9). No dose-response for elbow pain or physician observed epicondylitis.

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	95% CI	Comments
Dimberg 1987	Cross-sectional	A questionnaire was distributed to every fifth person in the automobile company's personnel file selected by random numbers. Final sample consisted of 546 workers, 494 males and 52 females. (25 were excluded due to military service, pregnancy, or study away).	Outcome: Only workers reporting elbow problems were examined by the physician. Physical exam: case defined as physical findings of lateral elbow pain and pain with palpation over lateral epicondyle and pain increase with dorsiflexion of wrist with resistance. Exposure: Observation of the work site then categorization of jobs "with respect to elbow stress" by a Physical Work Stress Group composed of a physician, physiotherapist, and safety engineer. Table 2 in the article lists types of jobs with respect to subjects's elbow stress.	Lateral humeral epicondylitis among all subjects: 7.4% Blue collar workers: 5.3% White collar workers: 11% Blue collar: under age 40 years: 4.6% Blue collar: over age 40 years: 8.9% White collar: under age 40 years: 6.1% White collar: over age 40 years: 13.9%	õ	Epicondylitis, blue vs. white collar workers: 0.7 Distribution of epicondylitis cases by type of work stress: Leisure related epicondylitis: low work stress: 85%; medium work stress: 15%; high work stress: 0% No-known-cause group: epicondylitis: low work stress: 75%; medium work stress: 25%; high work stress: 0% Work-related epicondylitis: low work stress: 14%; medium work stress: 36%; high work stress: 50%	0.3-1.2	Participation rate: 98.9%. Physician blinded to exposure status: not reported. Results age stratified. Physician-consulted elbow pain significantly greater in jobs with increased elbow stress. Work considered to be the cause in 35%. Authors found that work-related group had work defined by high stress (categorized by low, moderate, and high) compared to leisure-related epicondylitis and epicondylitis of no-known-cause. Authors reported that proportion of workers who consulted a physician for their elbow problems was significantly greater with increasing elbow stress ($p < 0.05$). Multiple regression analyses included gender, employee category, age, and degree of stress as independent variables—only age significantly related to prevalence. Overexertion of the extensor muscles of the wrist due to gripping and twisting movements prior to onset was verified in 28 (70%) of those with epicondylitis. Tennis players among "sufferers": 15% total population: 12%. All racquet sports: 20% among sufferers, 15% among total population.

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Dimberg et al. 1989	Cross-sectional	2,814 automotive workers, both blue- and white-collar workers: 2,423 males, 382 females.	Outcome: Questionnaire results of elbow trouble (pain, ache, discomfort) preventing normal work in last 12 months. Physical exam performed on 615 of 641 symptomatic workers. Epicondylitis: tenderness at the lateral/medial epicondyle and pain with resistance. Exposure: Observation of jobs, then classification into 3 Physical Work Stress Groups by physician, physiotherapist, and safety engineer. Guidelines for classification with respect to the strain on the subject's neck and upper extremities listed for light, moderately heavy, and heavy work included in article.	Blue collar	White collar	Univariate Results: *p*<0.001: higher age; longer time in present job; ponderal index, more symptoms; more mental stress at the onset of symptoms. *p*<0.05: salaried staff vs. others; heavy weight; less racquet sports, more symptoms. *p*<0.01: vibrating hand tools, more symptoms; time in present job, more symptoms. *p*>0.05: gender; strain group; full time; hrs/week; piece-work; fixed pay; smoking, house-owner.		Participation rate: 96%. Not stated whether examiner blinded to exposure status. Multivariate analysis performed, although the confounders controlled for were not stated by authors, nor were ORs presented. Vibrating tools, ponderal index, and mental stress at work listed as significant. Guidelines for classification of jobs as listed in the article do not seem to reflect increasing elbow stress. Group 1 includes "repeated rotation of the forearms and wrists occurs sporadically"; Group 2 includes less specifically "large and frequent rotations in extreme positions"; Group 3 does not include any reference to repeated rotation or extreme position of the forearms or wrists. The classification used seems unlikely to pick up increased elbow stress that would reflect higher strain and risk of epicondylitis. Increased ponderal index correlated with elbow symptoms in multivariate analysis. Mental stress at work with the onset of symptoms correlated with right-sided lateral epicondylitis. Mental stress variables not uniformly collected, so this may impact interpretation.

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Fishbein et al. 1988	Cross-sectional (mailed survey)	2212 musicians performing on a regular basis with one or more of the International Conference of Symphony and Opera Musicians (ICSOM). Total population of the membership was 4,025 musicians in 48 ICSOM orchestras. One orchestra did not participate.	Outcome: Outcome based on self-reported responses from survey. Self-reported elbow pain, with severity defined in terms of the effect of the problem on the musician's performance. Exposure: Questionnaire responses to orchestral instrument, age they began playing, age they joined the orchestra, number of weeks each year spent playing professionally.	10% right elbow: 6 % severe 8% left elbow: 4% severe	♂	Severe medical problem and its affect on performance, females vs. males: OR=2.04	1.6-2.6	Participation rate: 55%. Low response rate due to the fact that many orchestras were not in season at the time of the survey. Statistical weighting performed; "severe" pain was defined as pain that affects performance. Health habits, such as extent of exercise, use of cigarettes, alcohol, beta blockers, and other drugs. Average age beginning playing instrument is 10 years. Average age joining a professional orchestra is 23 years. Average age: male musicians–43 years, female musicians–40 years. Severe problems were more likely in ages under 35 than over 45 years. Authors speculated that musicians with severe problems leave the orchestra. Low participation rate limits interpretation.

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Hales et al. 1994	Cross-sectional	518 telecommunication workers (416 females and 117 males). Workers fulfilling outcome definition compared to those not fulfilling outcome definition.	Outcome: Pain, aching, stiffness, burning, numbness, or tingling >1 week or >12 times a year; occurring after employment on current job within the last year and positive physical examination (PE): Moderate to worst pain experienced with medial or lateral epicondyle palpation. Exposure: Assessed by questionnaire. Questions addressed number of overtime hr, co-worker use of same workstation, task rotation, hr spent at the (VDT) workstation, hr spent typing, number and types of work breaks, length of time sitting, frequency of arising from a chair, number of keystrokes estimated for each directory assistance operator.	7%	ð	Fear of being replaced by computers: OR=2.9 Lack of decision-making opportunities: OR=2.8 Surges in workload: OR=2.4 Race (non-white) OR=2.4	1.4-6.1 1.4-5.7 1.2-5.0 1.2-5.0	Participation rate: 93%. ORs for psychosocial represent risk at scores one standard deviation (SD) above the mean compared to risk at scores one SD below mean. May be a problem with non-normal distribution. Analysis controlled for age, gender, individual factors, and number of keystrokes/day. Physician examiners blinded to case and exposure status. Although keystrokes/day was not significant–workers only typed average of 8 words/min over 8-hr period. 97% of workers "used" VDTs $ 6 hr/day–not enough variance to adequately evaluate hr typing. Number of hr on hobbies and recreation not significant. Over 70 variables analyzed in models–may have multiple comparison problem.

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	Referent group	RR, OR, or PRR	95% CI	Comments
Hoekstra et al. 1994	Cross-sectional	108 of 114 teleservice representatives working at 2 government administration centers: A and B.	Outcome: Self administered questionnaire. Case defined as the presence of pain, numbness, tingling, aching, stiffness, or burning in the elbow region as previous non-occupational injury; symptoms began after starting the job, last > 1 week or occurred once a month within the past year; reported as “moderate” (3) or greater on a 5-point scale. Exposure: Measurement and evaluation of work station; observation of postures to provide descriptive differences between the two locations.	Center A Center B	19% 21%	"Non-optimally" adjusted chair: 4.0	õ 1.2-13.1	Participation rate: 95%. Analysis controlled for gender. Interactions evaluated. Variables considered in logistic model included location, age, seniority, hr spent typing at VDT, hr on the phone, 3 chair variables: (1) Perceived adequacy of chair adjustment, VDT screen, (2) Perceived adequacy of keyboard adjustment, VDT screen, (3) Perceived adequacy of desk adjustment, job control, workload variability. Linear regression also performed on psychosocial variables in separate models for job dissatisfaction and exhaustion. Center B generally had nonadjustable chairs and work stations. Authors noted elevated arms, hunched shoulders and other "undesirable" postures. Did not include non-work-related variables in analyses.

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

				MSD prevalence				
Study	**Study design**	**Study population**	**Outcome and exposure**	**Exposed workers**	**Referent group**	**RR, OR, or PRR**	**95% CI**	**Comments**
Hughes and Silverstein 1997	Cross-sectional	104 male aluminum smelter workers: 62 carbon setters, 36 crane operators, 9 carbon plant workers. There were 14 workers who were not from selected jobs and were excluded.	Outcome: Symptoms occurring in the elbow/forearm > once/month or lasting longer than one week in the previous year, no acute or traumatic onset; occurrence since working at the plant, no systemic disease. Physical examination: Active, passive, and resisted motions, pinch and grip strength, 128 Hz vibration sensitivity, two-point discrimination. Psychosocial scales from questionnaire based on Theorell and Karasek Job Stress Questionnaire, and on Work Apgar Questionnaire. Exposure: For carbon setters and crane operators (non-repetitive jobs) a modified job-surveillance checklist method was used. Job task analysis used a formula based on the relative frequency of occurrence of postures during (a) task(s).	11.6% with positive symptoms and physical exam 24% had symptoms in the elbow/forearm in the previous week	ŏ	Model based on MSD defined by symptoms and physical exam Age: OR=0.96 Low decision latitude: OR=3.5 Years of forearm twist: OR=37 Model based on MSD defined by symptoms Age: OR=0.96 Years of ulnar deviation: OR=0.005 Years forearm twist: OR=4	0.9-1.2 0.6-19 3.0-470 0.9-1.2 0.0-16 0.18- 4	Participation rate: Carbon setters: 65%; crane operators: 56%; carbon plant: 33%. Examiners blinded to exposure and health status: not stated. Analysis controlled for age, smoking status, sports, and/or hobbies. Psychosocial data collected individually; physical factors based on estimates of each job. Job risk factors entered into the model for hand/wrist included: (1) the number of years handling > 2.7 kg/hand, (2) push/pull, (3) lift/carry, (4) pinching, (5) wrist flexion/extension, (6) ulnar deviation, and (7) forearm twisting. Health interview included information about metabolic diseases, acute traumatic injuries, smoking, hobbies. Low participation rate limits interpretation.

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Kopf et al. 1988	Cross-sectional	Bricklayers (n=163) compared to other manual workers (n=144) employed by state agencies in Hamburg, Germany.	Outcome: Questionnaire based, self-reported symptoms. Self-reported pain in the elbow. Exposure: Based on job categories, bricklayer vs. other manual laborers. Physical stress of bricklayers described as lifting and carrying bricks weighing 5 to 24 kg up to 100 times/hr with the left hand and handling the bricklayer's trowel with the right hand.	Not reported	Not reported	Painful left elbow, bricklayers vs. other manual workers: OR=2.8	Not reported	Participation rate: bricklayers: 65%, manual workers: 69%. Controlled for confounders: age, job satisfaction, job security, vibration, moistness, Scheuerman's disease. Karasek's model of job latitude and job demands were included in the questionnaire. Physically demanding previous tasks, medical disposition for MSD, being a member of a trade union included in analysis. 64% attributable risk proportion of elbow pain is explained by being a bricklayer. For increasing levels of job demands (heavy physical work, awkward working positions, repetitive movements, and restriction in standing position), OR increased from 1.8 to 3.4.

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Kurppa et al. 1991	Cohort; 31 month follow-up	Sausage makers (107 females) compared to nonstrenuous jobs (197 females). Meatcutters (102 males) compared to nonstrenuous jobs (n=141). Packers (118 females) compared to nonstrenuous jobs (197 females).	Outcome: Tenderness to palpation of the epicondyle and epicondylar pain provoked by resisted extension or flexion of the wrist and fingers with the elbow extended. Incidence based on visits to doctor during 31 month visit. Disease considered "new" episode if new sick leave with same diagnosis occurred at same anatomic site within 60 days after end of former sick leave. Exposure: Data obtained from "previous published literature" and walkthrough. "Cutting of veal (appx. 1,200 kg/day) or pork (appx. 3,000 kg/day) (meatcutters); spraying the sausages and hanging them on bars (sausage makers); peeling sausages, inserting them into slicing machine, setting the slices into packages, setting packages on a conveyor belt, collecting finished packages into bags; room temperature 8E to 10E (packers); nonstrenuous tasks included primarily office work."	Sausage makers (females): 11.1 cases/100 person-years Meatcutters (males): 6.4 cases/100 person-years Packers (males): 7.0 cases/100 person-years	Workers in Non-strenuous jobs: 1.1 cases /100 person-years Workers in non-strenuous jobs: 0.9 cases/100 person-years Workers in Nonstrenu-ous jobs: 1.1 cases/100 person-years	IR of males in strenuous jobs vs. nonstrenuous jobs: 5.7 IR of females in strenuous jobs vs. nonstrenuous jobs: 8.1 IR of total number of cases of epicondylitis in strenuous jobs vs. nonstrenuous jobs: 6.7	3.3-13.9	Participation rate: 93% of strenuous workers retained during study; 90% of nonstrenuous workers. Examiners blinded to exposure or past episodes: not reported. Diagnoses made by different physicians at different locations. Plant physicians agreed to the diagnostic criteria and made 75% of diagnoses. 25% of physicians were not involved in agreement of diagnostic criteria. 13% of epicondylitis diagnosed by consulting specialists at the nearby medical center, 12% elsewhere, usually at municipal health centers. No adjustment for confounders, but referent group selected similar to strenuous group with regards to age, gender, and duration of employment, except for male sausage makers and male packers who were younger than the rest of the study population–these were excluded from calculations of incidence rates. "New" episode of epicondylitis may be recurrence of same disease. 12 employees reafflicted with epicondylitis with median of 184 days between episodes. There were 68 diagnoses of epicondylitis among 57 individuals.

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Luopajärvi et al. 1979	Cross-sectional	Female assembly line workers (n=152) compared to female shop assistants in a department store (n=133). Cashiers excluded from comparison group.	Outcome: Epicondylitis diagnosed by interview and physical exam. Symptoms include muscle pain during effort, local swelling, and local ache at rest. Signs include tenderness at the ateral or medial epicondyle on palpation, pain during resisted extension/flexion of the wrist and fingers with the elbow extended. Physiotherapist examined workers, diagnoses were from pre-determined criteria (Waris 1979). In problem cases orthopedic and physiatric teams handled cases. Exposure: Exposure to repetitive work, awkward hand/arm postures, and static work assessed by observation, video analysis and interviews. Video recordings showed repetitive motins of the hands and fingers up to 25,000 cycles/day, static muscle loading of the forearm muscles, and deviations of the wrist, lifting.	5.9%	2.3%	2.7	0.66-15.9	Participation rate: 84%. Workers excluded from participation for previous trauma, arthritis and other pathologies. Examiner blinded to case status: yes, according to the Waris et al. 1979, epidemiologic screening procedure, which was used in study. No association between age and MSDs or length of employment and MSDs. Gender not an issue because study population was all female. Factory opened only short time so no association between duration of employment and MSDs possible. Social background, hobbies, amount of housework not significant.

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
McCormack et al. 1990	Cross-sectional	Randomly selected population of 2,261 textile workers from 8,539 eligible workers; 4 groups compared with 468 non-office workers Manufacturing workers: A. Packaging/folding workers (41 males, 238 females). B. Sewing workers (28 males, 534 females). C. Non-office workers (204 males, 264 females). D. Boarding workers (19 males, 277 females).	Outcome: Based on physician administered physical exams. Reproducible tenderness with direct pressure on the lateral epicondyle. Severity graded as mild, moderate, and severe. Exposure: Assessment by observation of jobs. Exposure to repetitive finger, wrist and elbow motions assumed from job title; no objective measurements performed.	Boarding workers: 1.0% Sewing workers: 2.1% Packaging/ folding workers: 2.2% Knitting: 1.4%	Non-office workers: 1.9%	Boarding vs. non-office: OR=0.5 Sewing vs. non-office: OR=1.1 Packaging vs. non-office: OR=1.1 Knitting vs. non-office: OR=1.2	0.09-2.1 0.4-2.9 0.4-3.2 0.5-3.4	Participation rate: 91%. Physician or nurse examiners not blinded to case or exposure status (personal communication). Age, gender, race, and years of employment analyzed. Prevalence higher in workers with < 3 years of employment. Questionnaire asked types of jobs, length of time on job, production rate, nature and type of upper extremity complaint, and general health history. 11 physician examiners; interexaminer reliability potential problem acknowledged by authors. Epicondylitis significantly associated with years of employment, age, race. Job category not related to epicondylitis, however no measurement of force, repetition, posture analysis, etc. Of 37 cases of epicondylitis identified: 13 were categorized as mild, 22 were moderate, and 2 were severe.

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	95% CI	Comments
Moore and Garg 1994	Cross-sectional	Workers employed in 32 jobs at a pork processing plant (n=230). Workers in jobs classified as "hazardous" compared to those in "safe" jobs.	Outcome: OSHA logs verified by medical records data for 20 months. Epicondylitis: localized elbow pain that increased with tension of muscle-tendon unit and direct palpation. A case required that a physical examination specific to epicondylitis was performed. Exposure: Observation and video analysis, semi-quantitative methods using motion and time methods (MTM), force estimated as % maximal strength (5 levels), wrist posture (3 levels), type of grasp (2 levels), high speed work (yes or no), localized mechanical compression (yes or no), vibration (yes or no), and cold (yes or no). Observed videotaped representative worker in each job. Repetition as cycle-time and exertions/min measures. Jobs classified as "hazardous" or "safe" based on data, experience of authors, and judgements. Work histories, demographic, pre-existing morbidity data not collected on each participant.	Workers in "hazardous jobs": 23%	Workers in "safe jobs": 3%	Odds of epicondylitis in workers in "hazardous jobs" compared to workers in "safe jobs": OR=5.5 (based on personal communi-cation)	1.5-62	Participation rate: Cases identified from medical records. Jobs analyzed from observational methods. Investigators blinded to exposure, case outcome status, and personal identifiers on medical records. Repetitiveness and "type of grasp" were not significant factors between hazardous- and safe-job categories. No pattern of morbidity accord-ing to date of clinic visits. Strength demands significantly greater for hazardous job categories compared to safe. IR based on full-time equivalents and not individual workers, may have influenced overall results. Workers had a maximum of 32 months of exposure at plant–duration of employment analysis limited. Duration of exposure not collected on study sample. Average maximal strength derived from population-based data stratified for age, gender, and hand dominance. Using estimates of Silverstein's classification, association between forcefulness, and overall observed morbidity was statistically significant; repetition was not. 31 of 32 jobs were in high repetitive category–no variance to find difference.

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	RR, OR, or PRR	95% CI	Comments
Ohlsson et al. 1989	Cross-sectional	Electrical equipment and automobile assemblers (n=148), former female assembly workers who quit within 4 years (n=76) compared to randomly sampled females from general population (n=60).	Outcome: Questionnaire: Any elbow pain, elbow pain affecting work ability, and elbow pain in the last seven days and the last 12 months. Exposure: No exposure measurements; based on job categorization. Work pace divided into 4 classes: (1) Slow <100 items/hr; (2) Medium 100 to 199 items/hr; (3) Fast 200 to 700 items/hr; (4) Very Fast >700 items/hr.	Elbow pain in last 12 months: 21%	Elbow pain in last 12 months: 17%	1.5	0.6-3.4	Participation rate: Not reported. Work pace assessed by questionnaire, the number of items completed/hr. No association between length of employment and elbow symptoms. No statistical significance associated with work pace (data not present). Logistic models evaluated for interaction and controlled for age. Study group consisted of females only.
				Elbow pain in last 7 days: 14%	Elbow pain in last 7 days: 11%	1.9	0.7-5.3	
				Work inability in last 12 months: 10%	Work inability in last 12 months: 3%	2.8	0.8-10.7	

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Punnett et al. 1985	Cross-sectional	162 female garment workers, 85% were employed as sewing machine operators and sewing and trimming by hand. Comparison: 76 of 190 full or part-time workers on day shift in a hospital who worked as nurses or aids; lab technicians or therapists; food service workers. Employees typing >4 hr/day excluded from comparison group.	Outcome: Self-administered questionnaire concerning symptoms Cases defined as the presences of persistent elbow pain, numbness or tingling (lasted for most days for one month or more within the past year); were not associated with previous injury; and, began after first employment in garment manufacturing or hospital employment. Key questions based on the arthritis supplement questionnaire of National Health and Nutrition Examination Survey (NHANES). Exposure: Self-administered questionnaire; # of years in the industry, job category, previous work history.	Garment workers: 6.5%	Hospital employees: 2.8%	Elbow Symptoms in Garment workers vs. Hospital employees: OR= 2.4 Persistent elbow pain in finishers vs. hospital employees: OR=5.6 Persistent elbow pain in underpresser vs. hospital employees: OR=5.0	1.2-4.2	Participation rate: 97% (garment workers), 40% (hospital workers). Analysis stratified for number of years employed, decade of age, native language. Health outcome based on symptoms alone for elbow MSDs. Age and length of employment not a predictor of risk of elbow MSDs. Prevalence of pain not associated with years of employment in garment workers. Non-English speakers significantly less likely to report pain (RR 0.6 ; $p<0.05$). Native English speakers significantly older than non-native English speakers ($p<0.03$).

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Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	95% CI	Comments
Ritz 1995	Cross-sectional	290 males from the public gas and water works of Hamburg, Germany examined during routine medical check-up at the company occupational health center. Employees, excluded if on sick leave, came for medical treatment, pre-employment checkups, or to file a worker's compensation claim.	Outcome: Physician diagnosed; required local tenderness to palpation at the epicondyle and pain during resisted movement of the wrist and fingers (extension or flexion of the wrist or fingers with an extended elbow) AND elbow pain during the lifting of a chair. Epicondylitis was categorized as severe (Grade II and Grade III) if both functional tests were positive and as moderate (Grade I) if only symptom was a severe tenderness to palpation or a moderate pain in the resistance test. Clinical signs of epicondylitis > Grade 0 at one or more of the four anatomical sites was considered sufficient for the diagnosis. Exposure: All current and former job titles evaluated by members of the team according to possible bio-mechanical strain to the elbow and grouped into categories of high, moderate, and non work-related exposure. Exposure categorization was based on company job descriptions, interviews with employees, and workplace observations. Exposure duration was defined for all subjects as the	41 employees: 14% had epicondylitis 11% fulfilled Waris's criteria for epicondylitis (Waris, 1979)		10 years of high exposure to elbow straining work for currently held job: OR=1.7 High exposure to elbow straining work for formerly held job: OR= 2.16 10 years of high exposure to elbow straining work for currently held job using diagnostic criteria for epicondylitis [Waris et al. 1979]: OR=1.89	1.0-2.7 1.1-4.3 1.2-3.1	Participation rate: Not reported. Examiner blinded to exposure status. Logistic regression model controlled for age, age-squared, and an indicator term for "history of cervical spine symptoms" (yes, no). The following variables tested for confounding: having ever played tennis, squash, other racquet sports, rowing, bowling, the duration of having played these sports, injuries involving the elbow joint, ponderal index, handedness, and former surgical treatment for epicondylitis. The variable "time in years since retiring from a job with high or moderate exposure" was retained in the model for workers formerly employed in high exposure jobs when duration of exposure was tricotomized. Mean length of employment was not significantly different between cases and non-cases. Increasing duration of current exposure increased the risk of being diagnosed with epicondylitis.

(Continued)

Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	95% CI	Comments
Roto and Kivi 1984	Cross-sectional	Meatcutters, (n=90) compared to construction workers (n=72) not exposed to repetitive movements.	Outcome: Defined by physical exam: local tenderness, pain during resisted extension/flexion of the wrist and fingers, and decreased hand grip power in comparison to other hand. Exposure: Based on job title (meatcutter vs. construction worker).	Meatcutters: 8.9%	Construction workers: 1.4%	6.4	0.99-40.9 p= 0.05	Participation rate: 100% for meat cutters, 94% for construction workers. Authors state that examiners were blinded to occupation of subjects because part of larger group of meat processing workers examined, but it is unclear whether construction foremen (referents) were examined separately. Serologic testing for rheumatoid arthritis was done to control for potential confounding (none detected). 7 additional meatcutters had local tenderness in epicondylar region. All with epicondylitis had > 15 years of employment. Authors stated that on average, meatcutters with epicondylitis had been exposed five years longer than other meatcutters, supporting the association with meatcutting.

(Continued)

Table 4–5 (Continued). Epidemiologic studies evaluating elbow musculoskeletal disorders

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Viikari-Juntura 1991b	Cross-sectional	All permanent workers exposed to repetitive and manually stressful tasks in a meatpacking plant (102 meatcutters, 150 packers, and 125 sausage makers) were compared to 332 workers in nonstrenuous jobs (supervisors, maintenance men, accountants, and office workers).	Outcome: Elbow trouble (pain, ache, discomfort) preventing normal work in last 12 months and physical exam: tenderness at the lateral/medial epicondyle and pain with resistance. Exposure: Based on observation: Meatcutters: High force/high repetition. Sausage makers: High repetition/low force with high force tasks. Packers: High repetition/low force with high force jobs. Nonstrenuous jobs, mainly office jobs. "Cutting of veal (appx. 1,200 kg/day) or pork (appx. 3,000 kg/day) (meatcutters); spraying the sausages and hanging them on bars (sausage makers); peeling sausages, inserting them into slicing machine, setting the slices into packages, setting packages on a conveyor belt, collecting finished packages into bags; room temperature 8E to 10E (packers); nonstrenuous tasks included primarily office work."	Epicondylitis: 0.8% Lateral: 0.6% Medial: 0.2%	Epicondylitis: 0.8% Lateral: 0.6% Medial: 0.3%	The Odds Ratio of epicondylitis in strenuous jobs vs. non-strenuous jobs: 0.88 Elbow Pain (without the physical exam): Male: 1.8 Female: 1.6	0.27-2.8 1.1-2.8 1.2-2.3	Participation rate: 94%. No adjustment for confounders in analysis. Authors stated that the comparison group was selected similar to the study group to sex, age, and duration of employment. Examiners blinded to case and exposure status. Male packers and male sausage makers younger and length of employment shorter than other groups. Palpation pressure increased on 2nd of cross-sectional examinations–may have influenced results. For female sausage makers, elbow pain for preceding 12 months increased with age and duration of employment. No such associations in other groups. Age and current occupational correlated (r=0.52) for female sausage makers. Cases were not excluded due to direct trauma.

CHAPTER 5
Hand/Wrist Musculoskeletal Disorders (Carpal Tunnel Syndrome, Hand/Wrist Tendinitis, and Hand-Arm Vibration Syndrome): Evidence for Work-Relatedness

Musculoskeletal disorders (MSDs) of the hand/wrist region have been separated into three components for the purpose of this review: (a) Carpal Tunnel Syndrome (CTS), (b) Hand/Wrist Tendinitis, and (c) Hand-Arm Vibration Syndrome (HAVS). Each of these are described with regard to the evidence for causality between workplace risk factors and development of MSDs.

CHAPTER 5a
Carpal Tunnel Syndrome

SUMMARY

Over 30 epidemiologic studies have examined physical workplace factors and their relationship to carpal tunnel syndrome (CTS). Several studies fulfill the four epidemiologic criteria that were used in this review, and appropriately address important methodologic issues. The studies generally involved populations exposed to a combination of work factors, but a few assessed single work factors such as repetitive motions of the hand. We examined each of these studies, whether the findings were positive, negative, or equivocal, to evaluate the strength of work-relatedness using causal inference.

There is **evidence** of a positive association between highly repetitive work alone or in combination with other factors and CTS based on currently available epidemiologic data. There is also **evidence** of a positive association between forceful work and CTS. There is **insufficient evidence** of an association between CTS and extreme postures. Individual variability in work methods among workers in similar jobs and the influence of differing anthropometry on posture are among the difficulties noted in measuring postural characteristics of jobs in field studies. Findings from laboratory-based studies of extreme postural factors support a positive association with CTS. There is **evidence** of a positive association between work involving hand/wrist vibration and CTS.

There is **strong evidence** of a positive association between exposure to a combination of risk factors (e.g., force and repetition, force and posture) and CTS. Based on the epidemiologic studies reviewed above, especially those with quantitative evaluation of the risk factors, the evidence is clear that exposure to a combination of the job factors studied (repetition, force, posture, etc.) increases the risk for CTS. This is consistent with the evidence that is found in the biomechanical, physiological, and psychosocial literature. Epidemiologic surveillance data, both nationally and internationally, have also consistently indicated that the highest rates of CTS occur in occupations and job tasks with high work demands for intensive manual exertion–for example, in meatpackers, poultry processors, and automobile assembly workers.

INTRODUCTION

In 1988, CTS had an estimated population prevalence of 53 cases per 10,000 current workers [Tanaka et al. (in press)]. Twenty percent of these individuals reported absence from work because of CTS. In 1994, the Bureau of Labor Statistics (BLS) reported that the rate of CTS cases that result in "days away from work" was 4.8 cases per 10,000 workers. The agency also reported that the median number of days away from work for CTS was 30, which is even greater than the median reported for back pain cases [BLS 1995]. In 1993, the incidence rate (IR) for CTS workers' compensation cases was 31.7 cases per 10,000 workers; only a minority of these cases involved time off of work [Washington State Department of Labor and Industry 1996]. These data suggest that about 5 to 10 workers per 10,000 workers will miss work each year due to work-related CTS.

In recent years, the literature relating occupational factors to the development of CTS has been extensively reviewed by numerous authors [Moore 1992; Stock 1991; Gerr et al. 1991; Hagberg et al. 1992; Armstrong et al. 1993; Kuorinka and Forcier 1995; Viikari-Juntura 1995]. Most of these reviews reach a similar conclusion—work factors are one of the important causes of CTS. One review [Moore 1992] found the evidence more equivocal, but stated that the epidemiologic studies revealed a fairly consistent pattern of observations regarding the spectrum and relative frequency of CTS [among other musculoskeletal disorders (MSDs)] among jobs believed to be hazardous. The epidemiologic studies which form the basis for these reviews are outlined in Tables 5a–1 to 5a–4 of this chapter.

Thirty studies of occupational CTS are listed on Tables 5a–5. Twenty-one are cross-sectional studies, six are case-control, and three involve a longitudinal phase; all have been published since 1979. We included one surveillance study [Franklin et al. 1991] because it has been included in many of the earlier reviews. The few earlier studies of CTS identified were clinical case series, or did not identify work place risk factors and were not included in the tables related to CTS.

OUTCOME AND EXPOSURE MEASURES

In four of 30 studies listed in Tables 5a–1 to 5a–4, CTS was assessed based on symptoms alone; in another nine studies, the case definition was based on a combination of symptoms and physical findings. Electrophysiological tests of nerve function were completed in 14 studies. Electrodiagnostic testing (nerve conduction studies) has been considered by some to be a requirement for a valid case definition of CTS, as is similarly used for a clinical diagnosis in individuals with CTS. A few studies which have looked at the relationship of occupational factors to CTS have used a health outcome based on electrodiagnostic testing alone [Nathan et al. 1988; Schottland et al. 1991; Radecki 1995.] However, some authors [Nilsson 1995; Werner et al. 1997] have discouraged the use of labeling workers as having “CTS” or “median nerve mononeuropathy” based on abnormal sensory nerve conduction alone (without symptoms). The reason for this view is illustrated in a recent prospective study by Werner et al. [1997]. On follow-up six to eighteen months after initial evaluation, they found that asymptomatic active workers with abnormal sensory median nerve function (by Nerve Conduction Studies [NCS]) were no more likely to develop symptoms consistent with CTS than those with normal nerve function. Studies which have used nerve conduction tests for epidemiologic field studies have employed a variety of evaluation methods and techniques [Nathan et al. 1988, 1994b; Bernard et al. 1993; Osorio et al. 1994]. Normal values for nerve conduction studies have also varied from laboratory to laboratory. NCS results have been found to vary with electrode placement, temperature, as well as age, height, finger circumference and wrist ratio [Stetson 1993], suggesting that “normal” values may need to be corrected for those factors.

Several epidemiologic studies have used a surveillance case definition of CTS based on symptoms in the median nerve distribution and abnormal physical examination findings using Phalen’s test and Tinel’s sign, and have not included NCS. Two recent studies [Bernard et al. 1993; Atterbury et al. 1996] looked at CTS diagnosis based on questionnaire and physical examination findings and its association with the “gold standard” of nerve conduction diagnosed median mononeuropathy. Both studies found statistically significant evidence to support the use of an epidemiologic CTS case definition based on symptoms and physical examination (not requiring NCS) for epidemiologic surveillance studies. Nathan

[1992a] also found a strong relationship between symptoms and prolonged sensory median nerve conduction. (It is important to note here that a case definition used for epidemiologic purposes usually differs from one used for medical diagnosis and therapeutic intervention.)

Researchers have relied on a variety of methods to assess exposure to suspected occupational risk factors for CTS. These methods include direct measurement, observation, self-reports, and categorization by job titles. Most investigators agree that use of observational or direct measurement methods increases the quality (both the precision and accuracy) of ergonomic exposure assessments, but these methods also tend to be costly and time consuming. In general, misclassification errors tend to dilute the observed associations between disease and physical workload [Viikari-Juntura 1995].

REPETITION

Definition of Repetition for CTS

For our review, we identified studies that examined repetition or repetitive work for the hand and wrist for CTS as cyclical or repetitive work activities that involved either 1) repetitive hand/finger or wrist movements such as hand gripping or wrist extension/flexion, ulnar/radial deviation, and supination or pronation. Most of the studies that examined repetition or repetitive work as a risk factor for CTS had several concurrent or interacting physical workload factors. Therefore, repetitive work should be considered in this context, with repetition as only one exposure factor, accompanied by others such as force, extreme posture, and, less commonly, vibration.

Studies Reporting on the Association of Repetition and CTS

Nineteen studies reported on the results of the association between repetition and CTS. Several studies in Table 5a-1 quantitatively measured [Moore 1992; Chiang et al. 1990, 1993; Silverstein et al. 1987] or observed [Stetson et al. 1993; Nathan et al. 1988, 1992a; Barnhart et al. 1991; Osorio et al. 1994] and categorized repetitive hand and wrist movements in terms of: a) the frequency or duration of tasks pertaining to the hand/wrist, b) the ratio of work-time to recovery time, c) the percentage of the workday spent on repetitive activities, or d) the quantity of work performed in a given time. The rest of the studies generally used job titles or questionnaires to characterize exposure.

Studies Meeting the Four Evaluation Criteria

Five epidemiologic studies of the hand/wrist area addressing repetitiveness and CTS [Chiang et al. 1990, 1993; Moore and Garg 1994; Osorio et al. 1994; Silverstein et al. 1987] met the four criteria. Chiang et al. [1990] studied 207 workers from 2 frozen food processing plants. Investigators observed job tasks and divided them into low or high repetitiveness categories of wrist movement based on cycle time, as previously described by Silverstein et al. [1987]. Jobs were also classified according to whether or not workers' hands were exposed to cold work conditions. The resulting exposure groups were:
Group 1–Not Cold, Low Repetitiveness (mainly office staff and technicians);
Group 2–Cold Exposure or High Repetitiveness; and Group 3–Cold Exposure and High Repetitiveness. CTS diagnosis was based on abnormal clinical examination and nerve conduction studies. Prevalence of CTS

was 3% in Group 1, 15% in Group 2, and 37% in Group 3. Statistical modeling that also included gender, age, length of employment, and cold resulted in an odds ratio (OR) of 1.87 (*p*=0.02) for CTS among those with highly repetitive jobs. The OR for CTS among those exposed to cold conditions and high repetitiveness was 3.32 (*p*=0.03). The authors cautioned that cold exposure may have at least partially acted as a proxy for forceful hand/wrist exertion in this study group.

Chiang et al. [1993] studied 207 workers from 8 fish processing factories in Taiwan. Jobs were divided into 3 groups based on levels of repetitiveness and force. The comparison group (low force/low repetitiveness) was comprised of managers, office staff, and skilled craftsmen (group 1). The fish-processing workers were divided into high repetitiveness or high force (group 2), and high force and high repetitiveness (group 3). Repetition of upper limb movements (not specifically the wrist) was defined based on observed cycle time [Silverstein et al. 1987]. CTS was defined on the basis of symptoms and positive physical examination findings, ruling out systemic diseases and injury. CTS prevalence for the overall study group was 14.5%. CTS prevalence increased from group 1, to group 2, and to group 3 (8.2%, 15.3%, and 28.6%, respectively), a statistically significant trend (*p*<0.01). Repetitiveness alone was not a significant predictor of CTS (OR 1.1). Statistical modeling showed that women in this study group had a higher prevalence of CTS than men (OR 2.6, 95% confidence interval [CI] 1.3–5.2). Because the proportion of women varied by exposure group (48%, 75%, and 79% from group 1 to 3), further analyses were limited to females. The OR for repet-itiveness was 1.5 (95% CI 0.8–2.8), con-trolling for oral contraceptive use and force.

Moore and Garg [1994] evaluated 32 jobs in a pork processing plant and then reviewed past OSHA illness and injury logs and plant medical records for CTS cases in these job categories. A CTS case required the recording of suggestive symptoms (numbness and tingling) combined with electrodiagnostic confirmation (as reported by the attending electromyographers) of a case. Incidence ratios (IRs) were calculated using the full-time equivalent number of hours worked reported on the logs. The exact number of workers was not reported. Exposure assessment included videotape analysis of job tasks for repetitiveness and awkward postures. The force measure was an estimate of the percent maximum voluntary contraction (%MVC) based on weight of tools, and parts and population strength data adjusted for extreme posture or speed. Jobs were then categorized as hazardous or safe (for all upper extremity MSDs, not for CTS), based on exposure data and the judgment of the investigators. The hazardous jobs had a relative risk (RR) for CTS of 2.8 (95% CI 0.2–36.7) compared to the safe jobs. Due to the lack of data from individual workers, the study was unable to control for common confounders. Potential for survivor effect (79% of the workforce was laid off the year prior to the study), a limited latency period (8–32 months), and the potential for incomplete case ascertainment (underreporting is known to be a problem with OSHA illness and injury logs) limit confidence in this estimate. This study did not specifically address the relationship between repetitiveness and CTS. No significant association was identified between repetitiveness and the grouped "upper extremity musculoskeletal disorders," but there was very little variability in repetitiveness (31 of the 32 jobs had a cycle time less than 30 seconds).

Osorio et al. [1994] studied 56 supermarket workers. Exposure to repetitive and forceful wrist motions was rated as high, moderate, or low, following observation of job tasks. The CTS case definition was based on symptoms and nerve conduction studies. CTS-like symptoms occurred more often (OR 8.3, 95% CI 2.6–26.4) among workers in the high exposure group compared to the low exposed group. The odds of meeting the symptom and NCS-based CTS case definition among the high exposure group were 6.7 (95% CI 0.8–52.9), compared to the low exposure group.

Silverstein et al. [1987] studied 652 workers in 39 jobs from 7 different plants (electronics, appliance, apparel, and bearing manufacturing; metal casting, and an iron foundry). Investigators divided jobs into high or low repetitiveness categories, based on analysis of videotaped job tasks of 3 representative workers in each job. High repetitiveness was defined as cycle time less than 30 seconds or at least 50% of the work cycle spent performing the same fundamental movements. Jobs were also divided into high or low force categories based on EMGs of representative workers' forearm flexor muscles while they performed their usual tasks. EMG measurements were averaged within each work group to characterize the force requirements of the job. High force was defined as a mean adjusted force >6 kg. Jobs were then classified into 4 groups: low force/low repetitiveness, high force/low repetitiveness, low force/high repetitiveness, and high force/high repetitiveness. Fourteen cases (2.1% prevalence) of CTS were diagnosed based on standardized physical examinations and structured interviews.

The OR for CTS in highly repetitive jobs compared to low repetitive jobs, irrespective of force, was 5.5 ($p<0.05$) in a statistical model that also included age, gender, years on the job, and plant. The OR for CTS in jobs with combined exposures to high force and high repetition was 15.5 ($p<0.05$), compared to jobs with low force and low repetition. Age, gender, plant, years on the job, hormonal status, prior health history, and recreational activities were analyzed and determined not to confound the associations identified.

Studies Meeting at Least One Criterion

Fourteen additional studies met at least one of the criteria.

Barnhart et al. [1991] studied ski manufacturing workers categorized as having repetitive or nonrepetitive jobs based on observational exposure methods for hand/wrist exposure. The participation rate for this study was below 70%. Three different case definitions were used for CTS based on symptoms, physical exam findings, and NCS using the mean median-ulnar difference in each group. Each case definition used the NCS results. The authors reported a significant prevalence ratio (PR) of 2.3 for the mean median-ulnar sensory latency nerve difference among those in repetitive jobs compared to those in non-repetitive jobs. However, the difference was found in the ulnar rather than in the median nerve. The median nerve latencies were not statistically different between the two groups.

Baron et al. [1991] studied CTS in 124 grocery store checkers and 157 other grocery store workers who were not checkers. The CTS case definition required symptoms that met pre-determined criteria on a standardized questionnaire and physical examinations. The OR for CTS among checkers was 3.7 (95% CI 0.7–16.7), in a model that included age, hobbies, second jobs, systemic disease, and obesity. Participation rates at the work sites were higher among the exposed group (checkers: 85% participation, non-checkers: 55% participation). After telephone interviews in which 85% of the non-checkers completed questionnaires, investigators reported that the proportion of non-checkers meeting the case definition did not increase.

Cannon et al. [1981] in a case-control study of aircraft engine workers did not find a significant association with the performance of repetitive motion tasks (OR 2.1, 95%CI 0.9–5.3), but found a significant association with self-reported use of vibrating hand tools, history of gynecologic surgery, and an inverse relationship with years on the job. One must assume from the article that "repetitive motion tasks" were defined by job title. The diagnosis of CTS was based on medical and workers' compensation records.

In English et al.'s [1995] case-control study of upper limb disorders diagnosed in orthopedic clinics, the case series included 171 cases of CTS and 996 controls. Exposure was based on self-reports; repetitiveness was defined as a motion occurring more than once per minute. The logistic regression model of CTS found significant associations with height (negative), weight (positive), presentation at the clinic as a result of an accident (negative), and two occupational factors:
1) uninterrupted shoulder rotation with elevated arm (OR 1.8, 95% CI 1.2–2.8) and 2) protection from repeated finger tapping (OR 0.4, 95% CI 0.2–0.7). The authors note that the latter observation presented "difficulties of interpretation." Limitations of this study concern the lack of exposure assessment for repetition, and the questionable reliability for reported limb movements as an accurate measure of repetition.

Feldman et al. [1987] studied electronic workers at a large manufacturing firm using a questionnaire survey and biomechanical job analysis. Four work areas with 84 workers were identified as "high risk" with highly repetitive and forceful tasks. Workers in these high risk areas had physical examinations and NCS. Sixty-two workers from the high risk area had repeat NCS one year later. Comparing these high risk workers to the others, one can calculate ORs for symptoms of numbness and tingling [OR 2.26 (p<0.05)] and a positive Phalen's sign [2.7 (p<0.05)]. Longitudinal NCS of workers in the high risk area showed significant worsening in the median motor latency and sensory conduction velocity in the left hand, and motor changes over a year's period, which the authors attributed to work exposure. A limitation of this study concerns inadequate exposure information about the extent of worker exposure to repetitive and forceful work.

McCormack et al. [1990] studied 1,579 textile production workers and compared them to 468 other nonoffice workers, a comparison group that included machine maintenance workers, transportation workers, cleaners, and sweepers. The textile production workers were divided into four broad job categories based on similarity of upper extremity exertions. No formal exposure assessment was conducted. Health assessment included a questionnaire and screening physical examination followed by a diagnostic physical examination. CTS was diagnosed using predetermined clinical criteria. The severity of cases was also reported as mild, moderate, or severe. The overall prevalence for CTS was 1.1%, with 0.7% in boarding, 1.2% in sewing, 0.9% in knitting, 0.5% in packaging/folding, and 1.3% in the comparison group. None of the differences were statistically significant. A statistical model that also included age, gender, race, and years of employment showed that CTS occurred more often among women in this study ($p<0.05$). Interpretation of these data, especially with a low prevalence disorder like CTS, is difficult since gender varied with job (94% of boarding workers were female, compared to 56% in the comparison group), and the comparison group (machine maintenance workers, transportation workers, cleaners and sweepers) may have also been exposed to upper extremity exertions. Interactions among potential confounders were not addressed, but they are suspected because of significant associations between race and three MSDs.

Morgenstern et al. [1991] mailed questionnaires to 1,345 union grocery checkers and a general population group. Exposure was based on self-reported time working as a checker. Symptoms of CTS were significantly associated with age and the use of diuretics, and nonsignificantly associated with average hours worked per week, and years worked as a checker. A positive CTS outcome was based on the presence of all four symptoms: pain in the hands or wrist, nocturnal pain, tingling in the hands or fingers, or numbness. The estimated attributable fraction of CTS symptoms to working as a checker was about 60%, using both a general population comparison group and a low exposed checker group. The limitations of this study are: 1) the use of an overly sensitive health outcome measure, for example, 32% of the surveyed population reported numbness; and 2) the use of self-reported exposure.

Nathan et al. [1988] studied median nerve conduction of 471 randomly selected workers from four industries (steel mill, meat/food packaging, electronics, and plastics manufacturing). Median nerve sensory latency values were adjusted for age for statistical analyses. Thirty-nine percent of the study subjects had impaired sensory nerve conduction, or “slowing” of the median nerve. The five exposure groups were defined as follows: Group 1 is very low force, low repetition (VLF/LR); Group 2 is low force, very high repetition (LF/VHR); Group 3 is moderate force, moderate repetition (MF/MR); Group 4 is high force/moderate repetition (HF/MR); and Group 5 is very high force/high repetition (VHF/HR). There was no significant difference between Group 1 and Group 2, the groups that had the greatest differences in repetition. The authors reported a significantly higher number of subjects with median nerve slowing in Group 5 (VHF/HR) compared to Group 1 (VLF/LR), but not in other groups, using a statistical method described as a “pairwise unplanned simultaneous test procedure” [Sokal and Rohlf 1981]. The authors also reported that when individual hands were the basis of calculations rather than subjects, Group 3 had a significantly higher prevalence of median nerve slowing. Calculations of the data using PRs and chi-squares [Kleinbaum et al. 1982] resulted in significantly higher prevalences of median nerve slowing in each of Groups 3, 4, and 5 (moderate to high repetition, with moderate to very high force) compared to Group 1 (VLR/LF). PRs are 1.9 (95% CI 1.3–2.7), 1.7 (95% CI 1.1–2.5), and 2.0 (95% CI 1.1–3.4) for Groups 3, 4, and 5, respectively. A conservative (Bonferroni) adjustment of the significance level to 0.0125 for multiple comparisons [Kleinbaum et al. 1982] would result in Group 5 no longer being statistically significantly different from Group 1 (p=0.019), but Group 4 (p=0.009), and Group 3 (p=0.000) remain statistically significantly higher than Group 1 in prevalence of median nerve slowing.

In 1992, Nathan et al. [1992a] reported on a follow-up evaluation in the same study group. Sixty-seven percent of the original study subjects were included. Hands (630), rather than subjects, were the basis of analysis in this study. Novice workers (those employed less than 2 years in 1984) were less likely to return than non-novice workers (56% compared to 69%, p=.004). Maximum latency differences in median nerve sensory conduction were determined as in the Nathan et al. [1988] study. The authors state that there was no significant difference in the prevalence of median nerve slowing between any of the exposure categories in Nathan et al. [1988] using the same statistical method described in the Nathan et al. 1988 study. However, calculations using common statistical methods result in the following PRs for slowing: Group 3–1.5 (95% CI 1.0–2.2), Group 4–1.4 (95% CI 0.9–2.1), and Group 5–1.0 (95% CI 0.5–2.2), compared to Group 1. Group 5 had the same prevalence of slowing (18%) as Group 1 in 1989. In 1984 the prevalence of slowing was 29% in Group 5, and 15% in Group 1. The drop in prevalence of median nerve slowing in Group 5 between 1984 and 1989 might be explained by the higher drop-out rate among cases in Group 5 compared to Group 1 (PR 2.9, 95% CI 1.3–6.6). This was not addressed by the authors.

Punnett et al. [1985] compared the symptoms and physical findings of CTS in 162 women garment workers and 76 women hospital workers such as nurses, laboratory technicians, and laundry workers. Eighty-six percent of the garment workers were sewing machine operators and finishers (sewing and trimming by hand). The sewing machine operators were described as using highly repetitive, low force wrist and finger motions, whereas finishing work also involved shoulder and elbow motions. The exposed garment workers probably had more repetitive jobs than most of the hospital workers. CTS symptoms occurred more often among the garment workers (OR 2.7, 95% CI 1.2–7.6) compared to the hospital workers. There was a low participation rate (40%) among the hospital workers.

Schottland et al. [1991] carried out a comparison of NCS findings in poultry workers and job applicants as referents. No exposure assessment was performed, and applicants were not excluded if they had prior employment in the plant. Results indicated that the right median nerve sensory latency was significantly longer in 66 female poultry workers compared to 41 female job applicants. In these two groups of women there were less pronounced differences in the left median sensory latency. The latencies in the 27 male poultry workers did not differ significantly from the 44 male job applicants, although the power calculations presented in the paper noted limited power to detect differences among male participants. The OR for percentage of female poultry workers who exceeded the criteria value for the right median sensory latency is 2.86 (95% CI 1.1–7.9). The major limitations of this study are the absence of detailed information on exposure and the inclusion of former poultry workers into the applicant group, as well as the inadequate sample size, and the personal characteristics of these workers. This study found a significant association between highly repetitive, highly forceful work and abnormal NSC consistent with CTS. It does not allow analysis of repetition alone.

Stetson et al. [1993] used measurements of sensory nerve conduction velocity of the median nerve as indicators of nerve impairment or CTS; clinical examination results were not reported in this article. Three groups were studied: a reference group of 105 workers without occupational exposure to highly forceful or repetitive hand exertions, 103 industrial workers with hand/wrist symptoms, and 137 asymptomatic industrial workers. Exposure was assessed with a checklist by trained workers. Factors considered included repetitiveness (Silverstein criteria), force defined by the weight of an object that is carried or held, localized mechanical stress, and posture. Exposure assessments were available on 80% of the industrial workers. Most of the industrial workers were on repetitive jobs (76%), a minority carried more than ten pounds some of the time (32%), and gripped more than six pounds at least some of the time (44%). The analysis controlled for several confounders including age, gender, finger circumference, height, weight, and a square-shaped wrist. In the comparison of the asymptomatic to symptomatic industrial workers, the mean exposure for the symptomatic industrial workers was nonsignificantly slightly greater for all exposure factors except for repetitiveness. The median sensory amplitudes were significantly smaller ($p<0.01$) and latencies longer ($p<0.05$) for industrial workers with exposure to high grip forces compared to those without. Mean sensory amplitudes were significantly smaller ($p<0.05$) and motor and sensory latencies were significantly longer ($p<0.01$) in the industrial asymptomatic workers compared to the control group. These findings for the motor latencies are similar to Feldman et al. [1987]. Since most of the industrial workers were exposed to repetitive work, it is not clear whether this study population allowed a comparison between repetitive and non-repetitive work. Overall this study suggests that repetitive work combined with other risk factors is associated with slowing of median nerve conduction.

The Wieslander et al. [1989] case-control study used self-reported information collected via telephone interview about the duration of exposure (number of years and hours per week) to several work attributes including repetitive work. Definitions for these work attributes were not provided. Three categories of duration of exposure were defined for each attribute (<1 year, 1–20 years, and >20 years), but the asymmetry of the categories was not explained. A significant OR for reporting repetitive movements of the wrist comparing CTS patients to hospital referents (OR 4.6) and general population referents (OR 9.6) was reported, but only among those employed greater than 20 years. Those employed from 1–20 years compared to the referent population had elevated ORs for repetitive movements of the wrist (1.5 for CTS patients compared to hospital referents, and 2.3 compared to population referents), but these were not significant. Jobs with increasing numbers of work risk factors gave increasing ORs (from 1.7 to 7.1) among CTS cases when compared to referents; these were statistically significant when there were two or more risk factors. Given the limited quality of the exposure data and findings (repetition is a significant risk factor only after 20 years of exposure), this is only suggestive of a relationship between repetition alone and CTS.

Studies Not Meeting Any of the Criteria

Liss et al. [1995] conducted a mail survey concerning CTS among 2,124 Ontario dental hygienists compared to 305 dental assistants who do not scale teeth. Both groups had a low response rate (50%). The age adjusted OR was 5.2 (95% CI 0.9–32) for being told by a physician that you had CTS and 3.7 (95% CI 1.1–1.9) using a questionnaire-based definition of CTS. The major limitations of this study are the low participation rate, the lack of a detailed exposure assessment for repetitiveness, and self-reported health outcome.

Strength of Association—Repetition and CTS

Three of the five studies that met all four criteria evaluated the effect of repetitiveness alone on CTS: Chiang et al. [1990], Silverstein et al. [1987], and Chiang et al. [1993].

Chiang et al. [1990] reported an OR of 1.9 ($p<0.05$) for CTS among those with highly repetitive jobs. The OR for CTS among those exposed to high repetitiveness and cold was 3.32 ($p<0.05$). The additional effect attributed to cold may be at least partially explained by forceful motions among workers who were also exposed to cold. Force was not evaluated in this study.

Silverstein et al. [1987] reported an OR of 5.5 ($p<0.05$) for repetition as a single predictor of CTS. Among workers exposed to high repetition and high force, the OR was 15.5 ($p<0.05$).

Chiang et al. [1993] reported a significant trend of increasing prevalence of CTS with increasing exposure to repetition and/or force (8.2%, 15.3%, and 28.6%, $p<0.05$). Repetition (of the whole upper limb, not the wrist) alone did not significantly predict CTS (OR 1.1).

In summary, three studies that met all four criteria reported ORs for CTS associated with repetition. The statistically significant ORs for CTS attributed to repetition alone ranged from 1.9 to 5.5. The statistically significant ORs for CTS attributed to repetition in combination with force or cold ranged from 3.3 to 15.5. Gender, age, and other potential confounders were addressed and are unlikely to account for the associations reported.

Five other studies observed job tasks, then grouped them into categories according to estimated levels of repetitiveness combined with other risk factors [Feldman et al. 1987; Moore and Garg 1994; Nathan et al. 1988, 1992a; and Osorio et al. 1994]. CTS case definitions reported here required more than symptom-defined criteria. Moore and Garg [1994] reviewed medical records; Nathan et al. [1988] and Osorio et al. [1994] performed nerve conduction studies.

Feldman et al. [1987] reported an OR of 2.7 (*p*<0.05) for a positive Phalen's test among workers in high exposure jobs, compared to low exposure jobs.

Moore and Garg [1994] reported an OR of 2.8 (0.2, 36.7) for CTS among workers in "hazardous" jobs compared to workers in "nonhazardous" jobs.

Nathan et al.'s [1988] data result in PRs for four groups with varying levels of repetitiveness and force from very low (VL) to very high (VH), compared to a very low force, low repetition group (VLF/LR):
LF/VHR versus VLF/LR: 1.0 (95% CI 0.5–2.0)
MF/MR versus VLF/LR: 1.9 (95% CI 1.3–2.7)
HF/MR versus VLF/LR: 1.7 (95% CI 1.1–2.5)
VHF/HR versus VLF/LR: 2.0 (95% CI 1.1–3.4).

Nathan et al. [1992a] data, a 5-year follow-up of the 1988 study, result in PRs for the following groups:
LF/VHR versus VLF/LR: 1.0 (95% CI 0.6–1.9)
MF/MR versus VLF/LR: 1.5 (95% CI 1.0–2.2)
HF/MR versus VLF/LR: 1.4 (95% CI 0.9–2.1)
VHF/HR versus VLF/LR: 1.0 (95% CI 0.5–2.2).

Osorio et al. [1994] reported an OR of 6.7 (95% CI 0.8–52.9) for CTS among workers in high exposure jobs, compared to workers in low exposure jobs. Using a symptom-based case definition, the OR for the same comparison groups was 8.3 (95% CI 2.6–26.4).

To summarize, three of the five studies reviewed resulted in statistically significant positive findings for CTS associated with combined exposures. Feldman et al. [1987] reported an elevated OR for CTS with high combined exposure. Nathan et al.'s [1988] data resulted in elevated PRs for CTS among the three highest combined exposure groups. Nathan et al.'s [1992a] data resulted in an elevated PR for CTS among one of the high combined exposure groups. There was evidence of survivor bias in the highest exposure group.

The following studies used job title or job category to represent exposure to repetitiveness combined with other exposures and defined CTS based on physical examination [Baron et al. 1991, McCormack et al. 1990, Punnett et al. 1985] or nerve conduction studies [Schottland et al. 1991].

Baron et al. [1991] reported an OR of 3.7 (95% CI 0.7–16.7) for CTS, defined by symptoms and physical examination, among grocery checkers compared to other grocery workers.

McCormack et al. [1990] reported the following ORs for CTS among workers in each of four broad job categories that were considered exposed, compared to a comparison group of maintenance workers and cleaners that was considered to have low exposure:
Boarding versus Low: 0.5 (95% CI 0.1–2.9)
Sewing versus Low: 0.9 (95% CI 0.3–2.9)

Packaging versus Low: 0.4 (95% CI 0.0–2.4)
Knitting versus Low: 0.6 (95% CI 0.1–3.1)

Punnett et al. [1985] reported an OR of 2.7 (95% CI 1.2–7.6) for CTS among garment workers versus hospital workers.

Schottland et al. [1991] reported an OR of 2.86 (95% CI 1.1–7.9) for prolonged right median sensory latency among female poultry workers, compared to female applicants for the same jobs. No significant differences were identified among males.

In summary, two of the four studies reviewed above reported significantly elevated ORs for CTS or median sensory nerve conduction slowing.

Wieslander et al. [1989] reported an OR for CTS (surgical cases, confirmed by NCS) of 2.7 (95% CI 1.3–5.4) among those with self-reported exposure to repetitive wrist movement >20 years, compared to hospital referents, and 4.5 (95% CI 2.0–10.4), compared to population referents. Significant OR s for CTS among those with combined job risk factors ranged from 3.3 to 7.1.

The remaining two studies relied on self-reported symptoms and self-reported exposures from mail [Morgenstern et al. 1991] or telephone surveys [Liss et al. 1995]. Data quality and response rates limit interpretation of findings.

In conclusion, among the studies that measured repetition alone, there is evidence that repetition is positively associated with CTS. The majority of studies provide evidence of a stronger positive association between repetition combined with other job risk factors and CTS.

Temporal Relationship: Repetition and CTS

The question of which occurs first, exposure or disease, can be addressed most directly in prospective studies. However, study limitations such as survivor bias can cloud the interpretation of findings. In our analysis of Nathan et al.'s [1992a] data, 2 of 3 groups that were exposed to forceful hand/wrist exertions were more likely to have median nerve slowing when nerve conduction testing was repeated 5 years later. The highest exposure group had the same prevalence of slowing as the lowest exposure group in 1989, whereas they had a higher prevalence rate in 1984. As discussed above, this apparent decrease in prevalence over 5 years can probably be explained by a higher drop-out rate among cases in the highest exposure group, compared to the lowest exposure group. These interpretations of the data differ from those of the authors. Further study is needed to clarify these issues. However, to our knowledge, there is no evidence demonstrating that those with CTS would be more likely to be hired in jobs that involve high exposure to repetitive hand/wrist exertions and combined job risk factors, compared to those without CTS. In fact, employment practices tend to exclude new workers with CTS from jobs that require repetitive and intensive hand/wrist exertion.

Feldman et al. [1987] reported longer median motor (but not sensory) latencies among workers with combined exposure to hand/wrist exertion, compared to nerve conduction findings in the same group one year earlier.

Cross-sectional studies provide evidence that exposure occurred before CTS, by using case definitions that exclude pre-existing cases, and by excluding recently hired workers from the study. The studies that provide evidence that repetitive and combined job exposures are associated with CTS followed these practices, therefore the associations identified cannot be explained by disease occurring before exposure.

Consistency in Association for Repetition and CTS

One study [English et al. 1995] reported a statistically significant negative association between repetitive work and CTS. The specific exposure was self-reported repeated finger tapping; the investigators stated that they had difficulty interpreting this finding. All of the other statistically significant findings pointed to a positive association between repetitive work and CTS. The non-significant estimates of RR were also mostly greater than one.

Coherence of Evidence for Repetition

One of the most plausible ways that repetitive hand activities may be associated with CTS is thorough causing a substantial increase in the pressure in the carpal tunnel. This in turn can initiate a process which results in either reversible or irreversible damage to the median nerve [Rempel 1995]. The increase in pressure, if it is of sufficient duration and intensity, may reduce the flow of blood in the epineural venules. If prolonged, this reduction in flow may affect flow in the capillary circulation, resulting in greater vascular permeability and endoneural and synovial edema. Because of the structure of the median nerve and the carpal tunnel, this increase in fluid and resulting increase in pressure may persist for a long period of time. If the edema becomes chronic, then it may trigger a fibrosis which damages the function of the nerve. The interplay between acute increases in pressure and chronic changes to the nerve could partially explain why there is not a stronger correlation between symptoms of CTS and slowing of the median nerve. Both symptoms and slowing of the median nerve are likely to have both acute and chronic components in many cases of CTS.

The work determinants of pressure in the carpal tunnel are wrist posture and load on the tendons in the carpal tunnel. For example, the normal resting pressure in the carpal tunnel with the wrist in a neutral posture is about 5 millimeters of mercury (mmHg), and typing with the wrist in 45E of extension can result in an acute pressure of 60 mmHg. Substantial load on the fingertip with the wrist in a neutral posture can increase the pressure to 50 mmHg. A parabolic relationship between wrist posture and pressure in the carpal tunnel has been found. In laboratory studies of normal subjects, elevated carpal tunnel pressures quickly return to normal once the repetitive activity stops; patients with CTS take a long time for the pressure to return to their baseline values. One of the supporting observations for this model is that at surgery for CTS, edema and vascular sclerosis (fibrosis due to ischemia) are common [Rempel 1995].

This model of the etiology of work-related CTS is consistent with two observations from the epidemiological literature. First, it illustrates why both work and nonwork factors such as obesity may be important because anything that increases pressure in the carpal tunnel may contribute to CTS. Second, it explains why repetitiveness independent of wrist posture and load on the flexor tendons may not be a major risk factor for CTS.

Exposure-Response Relationship for Repetition

Evidence of an exposure-response relationship is provided by studies that show a correlation between the level or duration of exposure and either the number of cases, the illness severity, or the time to onset of the illness. Silverstein et al. [1987] showed an increasing prevalence of CTS signs and symptoms among industrial workers exposed to increasing levels of repetition and forceful exertion. This relationship was not seen when repetition alone was assessed. Similar findings on an exposure-response relationship were reported by Chiang et al. [1993], Osorio et al. [1994], Wieslander et al. [1989], and by Stock [1991] in her reanalysis of the Nathan et al. [1988] data.

Morgenstern et al. [1991] and Baron et al. [1991] reported increased prevalence of CTS with increasing length of time working as a grocery cashier.

Conclusions Regarding Repetition

Based on the epidemiologic studies noted above, especially those with quantitative evaluation of repetitive work, the strength of association for CTS and repetition has been shown to range from an OR of 2 to 15. The higher ORs are found when contrasting highly repetitive jobs to low repetitive jobs, and when repetition occurred in combination with high levels of forceful exertion. Those studies with certain epidemiologic limitations have also been fairly consistent in showing a relationship between repetition and CTS. The evidence from those studies which defined CTS based on symptoms, physical findings, and NCS is limited, due to the variety of methods used [Nathan et al. 1988; Stetson et al. 1993; Barnhart et al. 1991].

There is **evidence** of a positive association between highly repetitive work alone and CTS. There is **strong evidence** of a positive association between highly repetitive work in combination with other job factors and CTS, based on currently available epidemiologic data.

FORCE AND CTS

Definition of force for CTS

The studies reviewed in this section determined hand/wrist force exposure by a variety of methods. Some investigators [Armstrong and Chaffin 1979; Chiang et al. 1993; Silverstein et al. 1987] measured force by EMGs of representative workers' forearm flexor muscles while they performed their usual tasks. EMG measurements were averaged within each work group to characterize the force requirements of the job; jobs were then divided into low or high categories if the average force was above or below a cutoff point. Moore and Garg [1994] estimated force as %MVC, based on weight of tools and parts and population strength data, adjusted for extreme posture or speed. Jobs were then predicted to be either hazardous or safe (for any upper extremity musculoskeletal disorder), based on exposure data and judgment. Stetson et al. [1993] estimated manipulation forces based on weights of tools and parts and systematically recorded observations of one or more workers on each job. Jobs were then ranked according to grip force cutoffs. Nathan et al. [1988, 1992a] and Osorio et al. [1994] estimated relative levels of force (e.g., low, moderate, high) after observation of job tasks. McCormack et al. [1990] grouped jobs into broad job categories based on similarity of observed job tasks; one job group (boarding) required forceful hand/wrist exertions. Baron et al. [1991] and Punnett et al. [1985] used job title as a surrogate for exposure to forceful hand/wrist exertions.

Much of the epidemiologic data on CTS and force overlaps with those studies discussed in the above section on repetition. Repetitive work is frequently performed in combination with external forces, and much of the epidemiologic literature has combined these two factors when determining association with CTS.

Studies Reporting on the Association of Force and CTS

Eleven studies reported results on the association between force and CTS. The epidemiologic studies that addressed forceful work and CTS tended to compare working groups by classifying them into broad categories based on estimates of the forcefulness of hand/wrist exertions in combination with estimated repetitiveness. In most studies the exposure classification was an ordinal rating (e.g., low, moderate, or high); in some studies job categories or titles were used as surrogates for exposure to force exertions.

Studies Meeting the Four Evaluation Criteria

Four studies that evaluated the relationship between forceful hand/wrist exertion and CTS met all four criteria: Chiang et al. [1993], Moore and Garg [1994], Osorio et al. [1994], Silverstein et al. [1987]. Chiang et al. [1993] studied 207 workers from 8 fish-processing factories in Taiwan. Jobs were divided into 3 groups based on levels of force and repetitiveness. The comparison group (low force/low repetitiveness) was managers, office staff, and skilled craftsmen. The fish-processing workers were divided into high force or high repetitiveness (group 2), and high force and high repetitiveness (group 3). Hand force requirements of jobs were estimated by electromyographs of forearm flexor muscles of a representative worker from each group performing usual job tasks. High force was defined as an average hand force of >3 kg repetition of the upper limb (not specifically the wrist) was defined based on observed cycle time [Silverstein et al. 1987]. CTS was defined on the basis of symptoms and positive physical examination findings, ruling out systemic diseases and injury. CTS prevalence for the overall study group was 14.5%. CTS prevalence increased from group 1 to group 3 (8.2%, 15.3%, and 28.6%), a statistically significant trend $p<0.01$). Statistical modeling showed that women in this study group had a higher prevalence of CTS than men (OR 2.6, 95% CI 1.3–5.2). Force also significantly predicted CTS (OR 1.8, 95% CI 1.1–2.9), but not repetitiveness. Because the proportion of women varied by exposure group (48%, 75%, and 79% from groups 1 to 3), the possibility of an interaction between gender and job exposure exists, but this was not statistically examined. In an analysis limited to females, the 2 significant predictors of CTS were oral contraceptive use (OR 2.0, 95% CI 1.2–5.4), and force (OR 1.6, 95% CI 1.1–3.0). Concern over interpretation of these findings is raised because oral contraceptive use varies with age, and age may vary with job exposures.

These potential interactions were not examined, and women’s ages by job group were not reported.

Moore and Garg [1994] evaluated 32 jobs in a pork processing plant and then reviewed past OSHA 200 logs and plant medical records for CTS cases in these job categories. IRs were calculated using the full-time equivalent (FTE) number of hours worked as reported on the logs. The exact number of workers was not reported. Exposure assessment included videotape analysis of job tasks for repetitiveness and awkward postures. The force measure was an estimate of the %MVC, based on weight of tools and parts and population strength data, adjusted for extreme posture or speed. Jobs were then predicted to be either hazardous or safe (for all Upper Extremity MSDs), based on exposure data and judgment. CTS was determined by reviewing OSHA 200 logs and plant medical records. The proportion of CTS in the overall study group during the 20 months of case ascertainment was 17.5 per 100 FTEs. If the occurrence of CTS did not vary over this period, the proportion of CTS in a 12-month period would be 10.5 per 100 FTEs. The hazardous jobs had a RR for CTS of 2.8 (0.2, 36.7) compared to the safe jobs. Potential for survivor effect (79% of the workforce was laid off the year before the study), limited latency period (8-32 months), and the potential for incomplete case ascertainment (underreporting is common on OSHA 200 logs, and logs were not reviewed for the first 12 months of the study) limit confidence in this estimate. One of the more hazardous jobs, the Ham Loaders, required extreme wrist, shoulder and elbow posture and was rated 4 on a 5-point scale for force, yet there was no observed morbidity. Since this job did not start until 1989, the period of observation for musculoskeletal disorders for this job was only 8 months. Other jobs studied allowed for up to a 32-month latency period. The possibility of differential case ascertainment between exposed and unexposed jobs exists, both because of different observation periods, as well as the likelihood that turnover may have been greater in the exposed jobs. It is also unclear whether employees worked full-time or part-time hours.

Osorio et al. [1994] studied 56 supermarket workers. Exposure to repetitive and forceful wrist motions was rated as high, moderate, or low, following observation of job tasks (97% initial concordance with 2 independent observers). The CTS case definition was based on symptoms and nerve conduction studies. CTS-like symptoms occurred more often (OR 8.3, 95% CI 2.6–26.4) among workers in the high exposure group compared to the low exposed group. The odds of meeting the symptom and NCS-based CTS case definition among the high exposure group were 6.7 (95% CI 0.8–52.9), compared to the low exposure group.

Silverstein et al. [1987] measured force by electromyographs of representative workers' forearm flexor muscles while they performed their usual tasks. EMG measurements were averaged within each work group to characterize the force requirements of the job; jobs were then divided into high or low categories if the mean adjusted force was above or below 4 kg. Jobs were then classified into 4 groups that also accounted for repetitiveness: low force/low repetitiveness, high force/low repetitiveness, low force/high repetitiveness, and high force/high repetitiveness. Fourteen cases (2.1% prevalence) of CTS were diagnosed based on standardized physical examinations and structured interviews.

The OR for CTS in high force jobs compared to low force jobs, irrespective of repetitiveness, was 2.9 (p>0.05). The plant- adjusted OR for CTS in jobs with combined exposures to high force and high repetition was 14.3 (p<0.05), compared to jobs with low force and low repetition. Age, gender, plant, years on the job, hormonal status, prior health history, and recreational activities were analyzed and determined not to confound the associations identified. The OR for CTS in jobs with combined exposure from the multiple logistic analysis was 15.5 (95% CI 1.7–142.)

Studies Meeting at Least One Criterion

Baron et al. [1991] studied CTS in 124 grocery store checkers and 157 other grocery store workers who were not checkers. The CTS case definition required symptoms that met pre-determined criteria on a standardized questionnaire. Physical examinations were also performed, but participation rates at the work sites were higher among the exposed group (checkers: 85% participation, non-checkers: 55% participation). Telephone interviews to non-checkers resulted in questionnaire completion by 85% of the non-checkers. Based on a questionnaire case definition, the OR for CTS among checkers was 3.7 (95% CI 0.7–16.7), in a model that included age, hobbies, second jobs, systemic disease, and obesity.

McCormack et al. [1990] studied 1,579 textile production workers compared to 468 other nonoffice workers, a comparison group that included machine maintenance workers, transportation workers, cleaners, and sweepers. The textile production workers were divided into four broad job categories based on similarity of upper extremity exertions. The Boarding group required the most physical exertion. No formal exposure assessment was conducted. Health assessment included a questionnaire and screening physical examination followed by a diagnostic physical examination. CTS was diagnosed using predetermined clinical criteria. The severity of cases was also reported as mild, moderate or severe. The overall prevalence for CTS was 1.1%, with 0.7% in Boarding, 1.2% in Sewing, 0.9% in Knitting, 0.5% in Packaging/Folding, and 1.3% in the comparison group. None of the differences were statistically significant. A statistical model that also included age, gender, race, and years of employment showed that CTS occurred more often among women in this study (p<0.05). Interpretation of these data, especially with a low prevalence disorder like carpal tunnel syndrome, is difficult since gender varied with job (e.g., 94% of Boarding workers were female, compared to 56% in the comparison group), and the comparison group may have also been exposed to upper extremity exertions (machine maintenance workers, transportation workers, cleaners and sweepers). Interactions among potential confounders were not addressed, but they are suspected because of significant associations between race and three musculoskeletal disorders.

Nathan et al. [1988] studied median nerve conduction of 471 randomly selected workers from four industries (steel mill, meat/food packaging, electronics, and plastics manufacturing). Jobs were grouped into 5 relative levels of force (from very light to very high) after observation of job tasks. Jobs were also rated for repetitiveness (5 levels). Thirty-nine percent of the study subjects had impaired sensory conduction, or "slowing" of the median nerve. The 5 exposure groups were defined as follows: Group 1 is very low force, low repetition (VLF/LR); Group 2 is low force, very high repetition (LF/VHR); Group 3 is moderate force, moderate repetition (MF/MR); Group 4 is high force/moderate repetition (HF/MR); and Group 5 is very high force/high repetition (VHF/HR). The most logical comparisons to evaluate the effect of force would be Groups 3, 4, and 5 (moderate, high, and very high force) compared to Group 1 (low force). Group 2 jobs are not a good comparison because they are very highly repetitive, which may confound the comparisons. The authors reported a significantly higher number of subjects with median nerve slowing in Group 5 (VHF/HR) compared to Group 1 (VLF/LR), but not in other groups, using an uncommon statistical method (pairwise unplanned simultaneous test procedure [Sokal and Rohlf 1981]). The authors also reported that when individual hands were the basis of calculations rather than subjects, Group 3 had a significantly higher prevalence of median nerve slowing. Calculations of the more familiar PRs and chi-squares [Kleinbaum et al. 1982], using the published data, result in higher prevalences of median nerve slowing in each of Groups 3, 4, and 5, compared to Group 1 (PRs: 1.9, 95% CI 1.3–2.7; 1.7, 95% CI 1.1–2.5; and 2.0, 95% CI 1.1–3.4, respectively). A conservative adjustment (Bonferroni) of the significance level to 0.0125 for multiple comparisons [Kleinbaum et al. 1982] would result in Group 5 no longer being statistically significantly different from Group 1 (p=0.019), but Group 4 (p=0.009) and Group 3 (p=0.000) remain statistically significantly higher than Group 1 in prevalence of median nerve slowing.

In 1992 Nathan et al. [1992a] reported on a follow-up evaluation in the same study group. Sixty-seven per cent of the original study subjects were included. Hands (630), rather than subjects, were the basis of analysis in this study. Novice workers (those employed less than 2 years in 1984) were less likely to return than non-novice workers (56% compared to 69%, p=0.004). Probable CTS was defined on the basis of symptoms reported during a structured interview and a positive Phalen's or Tinel's test. Maximum latency differences in median nerve sensory conduction were determined as in the 1984 study. The authors state that there was no significant difference in the prevalence of slowing between any of the exposure categories in 1989. However, calculations using common statistical methods show significantly higher prevalences of slowing in Group 4 (PR 1.4, 95% CI 0.9–2.1) compared to Group 1. Group 3's prevalence of slowing was 26% compared to Group 1's 18%, but this difference was not statistically significant (p=0.07). Group 5 had the same prevalence of slowing (18%) as Group 1 in 1989; the prevalence of slowing in Group 5 was 29% in 1984. The drop in prevalence of slowing in Group 5 between 1984 and 1989 might be explained by the higher drop-out rate among cases in Group 5 compared to Group 1 (PR 2.9, 95% CI 1.3–6.6). This was not addressed by the authors.

Punnett et al. [1985] compared the symptoms and physical findings of CTS in 162 women garment workers and 76 women hospital workers such as nurses, laboratory technicians, and laundry workers. Eighty-six percent of the garment workers were sewing machine operators and finishers (sewing and trimming by hand). The sewing machine operators were described as using highly repetitive, low force wrist and finger motions, whereas finishing work also involved shoulder and elbow motions. The exposed garment workers likely had more repetitive jobs than most of the hospital workers. CTS symptoms occurred more often among the garment workers (OR 2.7, 95% CI 1.2–7.6) compared to the hospital workers. There was a low participation rate (40%) among the hospital workers.

Stetson et al. [1993] conducted nerve conduction studies on 105 administrative and professional workers, and 240 automotive workers. Hand/wrist forces were estimated based on weights of tools and parts and systematically recorded observations of one or more workers on each job. Jobs were then ranked according to grip force cutoffs: <6 lb, >6 lb, >10 lb. Median nerve measures differed among the groups: index finger sensory amplitudes were lower and distal sensory latencies were longer among automotive workers in jobs requiring grip force >6 lb and >10 lb, compared to those requiring less than 6 lb ($p<0.05$ for all). At the wrist, median sensory amplitudes were also lower and distal median sensory latencies were also longer among the >6 lb, and the >10 lb exposure groups ($p<0.05$ for 3 of 4 differences). Age, height, and finger circumference were included in statistical models. The automotive workers were then divided into two groups, symptomatic (n=103) and asymptomatic (n=137), based on whether or not they met standard interview criteria for CTS symptoms. When comparisons were made to the administrative and professional workers, 15 of 16 measures of median and ulnar nerve function showed lower amplitudes and longer latencies ($p<0.05$) among the asymptomatic automotive workers; differences were greater between the symptomatic automotive workers and the white collar workers. The symptomatic automotive workers had lower amplitudes and longer latencies for 5 of 6 median sensory measures ($p<0.05$), compared to the asymptomatic automotive workers; there were no significant differences in ulnar nerve function between these two groups. Asymptomatic automotive workers had "healthier" median nerves than automotive workers with CTS symptoms, but there were no differences between these 2 groups in ulnar nerve function, suggesting that the case definition was specific for CTS.

Of the studies that addressed CTS, almost all examined occupations and jobs in which force was combined with another exposure factor (such as repetition or awkward postures). Chiang et al. [1993] estimated exposure to hand/wrist force independent of repetitiveness and found statistically significant RRs for CTS ranging from 1.6 to 1.8. Estimates of RR that were not statistically significant ranged from 0.4 to 6.7 [McCormack et al. 1990; Osorio et al. 1994]. Relative risk estimates for CTS among workers exposed to a combination of forceful and repetitive hand/wrist exertions ranged from 1.0 to 15.5 [Nathan et al. 1988, 1992a; Silverstein et al. 1987].

Study limitations may impact the interpretation of findings. One limitation to consider is gender effect. Of the studies listed above reporting statistically significant associations between forceful hand/wrist exertions and CTS, gender effect was controlled for in the analyses. Other potential limitations such as selection factors impact the interpretation of the studies reviewed. Survivor bias can be a concern. If workers with CTS are more likely to leave jobs that require forceful and repetitive hand/wrist exertions than jobs without those demands, then the workers in the highest risk jobs may be "survivors" (those who did not get CTS). Our analysis of Nathan's [1992a] data from a follow-up of industrial workers shows that cases (with median nerve slowing) were more likely to drop out of the most highly exposed group than the unexposed group, which might explain why the RR for high exposure decreased from 2.0 to 1.0 over a 5-year period. Survivor bias results in an underestimate of the RR.

Refined or exact measures of exposure to forceful hand/wrist exertions are not always used in epidemiologic studies (e.g., sometimes exposure is based on job category and not actual forceful measurements); this can result in some study subjects being assigned to the wrong exposure category. When this occurs, the usual effect is again to underestimate the RR between exposure groups.

Stetson et al. [1993] did not report RR estimates for exposure variables, but they reported that median sensory amplitudes were significantly smaller and distal sensory latencies were significantly longer in groups with forceful hand exertions ($p<0.05$). Age, height, and finger circumference were included in statistical models.

Temporality, Force and CTS

Temporal issues can usually best be addressed using longitudinal studies. However, study limitations, such as survivor bias, can cloud the findings of even prospective studies. In our re-analysis of Nathan et al.'s [1992a] data, 2 of 3 groups exposed to forceful hand/wrist exertions were more likely to have median nerve slowing when nerve conduction testing was repeated 5 years later. The highest exposure group had the same prevalence of slowing as the lowest exposure group in 1989, whereas there had been a higher prevalence rate in 1984. As discussed above, this apparent decrease in prevalence over 5 years can likely be explained by survivor bias. Our interpretations of the data differ from those of the author. Further study is needed to clarify these issues. To our knowledge, there is no evidence that workers with pre-existing CTS are more likely to seek or to be employed in jobs with high force requirements. We believe that employment practices would, if they had any influence, tend to exclude new hires with CTS from jobs with high force requirements for the hand/wrist.

Case definitions in most of the cross-sectional studies excluded cases that occurred before working on the current job. This limits CTS cases studied to those that occurred following current exposure. Several of the studies reviewed also required a minimum time period of working on the job before counting CTS cases. This increases the likelihood that exposure to forceful hand/wrist exertion occurred for a sufficient length of time to develop CTS.

There is evidence that CTS is also attributable to nonwork causes (hobbies, sports, other medical conditions, and hormonal status in women, etc.). One issue which deals with temporality is whether those with nonwork-related CTS would be more likely to be hired into jobs requiring more forceful hand/wrist exertions than those without CTS. Again, it seems unlikely that those with pre-existing CTS would be preferentially hired into jobs requiring highly forceful hand/wrist exertions.

Consistency of Association for Force and CTS

Most of the statistically significant estimates of RR for CTS among workers with exposure to forceful hand/wrist exertions were positive. No studies found statistically significant negative associations between forceful hand/wrist exertions and CTS. One study reported ORs that were less than one among the groups that were described as exposed to repetitive hand movements; chance and study limitations cannot be ruled out as possible explanations for this finding. The other nonsignificant estimates of RR were, with one exception, greater than one.

Statistical significance can be a function of power (the ability of a study to detect an association when one does exist). In general, larger studies are necessary in order to have sufficient power to detect associations with rare diseases. CTS is a less frequently observed disorder than tendinitis, for example, and so larger studies are required to detect associations with confidence.

Coherence of Evidence, Force and CTS

Please refer to the Repetition and CTS Section.

Exposure-Response Relationship, Force and CTS

None of the studies reviewed demonstrated that increasing levels of force alone resulted in increased risk for CTS. The only evidence for an increasing risk for CTS that can be attributed to increasing levels of force alone is from a comparison across 2 studies that used the same methods. Chiang et al. [1993] and Silverstein et al. [1987] used the same methods to measure hand/wrist force requirements and repetitiveness of jobs. Chiang et al. [1993] used a lower cutoff point (3 kg compared to 4 kg) in Silverstein et al.'s [1987] study for classifying jobs as "high force"; these investigators used identical definitions of repetitiveness. Therefore, a comparison of the RR estimates between the 2 studies provides some information about the level of risk associated with different levels of force. Chiang et al. [1993] reported an OR of 2.6 (95% CI 1.0–7.3) for the high force and repetitive (HF/HR) (>3 kg) group (limited to females to avoid confounding) compared to the low force and repetitive (LF/LR) group; whereas Silverstein et al. [1987] reported an OR of 15.5 (95% CI 1.7–142) for the HF/HR group (in a statistical model that included gender, age, years on the job, plant and exposure level) compared to the LF/LR group. This comparison provides limited evidence of an increased RR for CTS with increasing level of hand/wrist force.

There is more evidence of a dose-response relationship for CTS with increasing levels of force and repetition combined. Chiang et al. [1993] reported a statistically significant trend of increasing prevalence of CTS with increasing exposure level (8.2% [LF/LR], 15.3% [HF or HR], and 28.6% [HF/HR], $p<0.01$). Silverstein et al. [1987] suggested a multiplicative effect when exposure to high force and high repetitiveness were combined (15.5), compared to high force (1.8) or high repetitiveness (2.7) alone.

Of the remaining nine studies, seven are consistent with the combined effect of force and repetition [Stetson et al. 1993; Moore and Garg 1994; Osorio et al. 1994; Armstrong and Chaffin 1979; Nathan et al. 1988; Punnett et al. 1985; Baron et al. 1991], one is not [McCormack et al. 1990]; and one is equivocal [Nathan et al. 1992a].

In conclusion, there is **evidence** that force alone is associated with CTS. There is **strong evidence** that a combination of forceful hand/wrist exertion and repetitiveness are associated with CTS.

POSTURE AND CTS

Definition of Extreme Postures For CTS

We selected those studies which addressed posture of the hand/wrist area including those addressing pinch grip, ulnar deviation, wrist flexion/extension. Posture is a difficult variable to examine in ergonomic epidemiologic studies. It is hypothesized that extreme or awkward postures increase the required force necessary to complete a task. Posture may increase or decrease forceful effort; its impact on MSDs may not be accurately reflected in measurement of posture alone. Reasons that the variable "extreme posture" has not been measured or analyzed in many epidemiologic studies are: 1) because of the extreme variability of postures used in different jobs as well as the extreme variability of postures between workers performing the same job tasks,
2) because several studies have taken into account the effects of posture when determining other measured variables such as force [Silverstein et al. 1987; Moore and Garg 1994]; and 3) stature often has a major impact on postures assumed by individual workers during job activities.

Studies Meeting the Four Evaluation Criteria

Two studies fulfilled the four criteria for posture and CTS: Moore and Garg [1994], Silverstein et al. [1987]. The overall study designs are mentioned above; the following section will cover the posture assessment.

For the exposure assessment of the posture variables in the Silverstein et al. [1987] study, three representative workers from each selected job performing the jobs for at least three cycles were videotaped using two cameras. The authors then extrapolated the posture data to non-observed workers.

Moore and Garg [1994] used a wrist classification system similar to that used by Stetson et al. [1993], classifying the wrist angle estimated from videotape as neutral, non-neutral or extreme if the flexion/extension angle was 0° to 25°, 25° to 45° and greater than 45°, respectively; or if ulnar deviation was less than 10°, 10° to 20°, and greater than 20°, respectively.

Strength of Association: Posture and CTS

Silverstein found no significant association between percentages of cycle time observed in extreme wrist postures or pinch grip and CTS. "CTS jobs" had slightly more ulnar deviation and pinching but these differences were not statistically significant. The authors noted that among all the postural variables recorded, the variability between individuals with similar or identical jobs was probably the greatest for wrist postural variables. This individual variation within jobs was not taken into account in the analysis, creating a potential for misclassification of individuals by using the variable "job category" in the analysis. The effect of exposure misclassification is usually to decrease differences between exposure groups and decrease the magnitude of association.

Moore and Garg's [1994] classification of jobs did not separate the posture variables from other work factors, and used posture along with other variables to classify jobs into "hazardous" and "safe" categories. The RR of CTS occurring in hazardous jobs was 2.8 but not statistically significant (p=0.44).

Studies Not Meeting All Four Evaluation Criteria

deKrom et al. [1990] compared certain exposure factors between 28 CTS cases from a community sample and 128 CTS cases from a hospital (a total of 156 CTS cases) to 473 community "non-cases" (n=473). The authors relied on self-reported information about duration of exposure (hours per week) to CTS risk factors (flexed wrist, extended wrist, extended and flexed wrists combined; pinch grasp and typing), with respondents recalling exposure from the present to 5 years prior from the questionnaire date. Four groups of duration were used in the analyses (0; 1–7; 8–19, 20–40 hours/week). In this study, the selection process of cases was not consistent. Initially, a random population sample was used, then hospital outpatients were used to supplement the number of CTS cases when numbers were found to be insufficient. This may be a problem when estimating the etiologic role of workload, as cases seeking medical care may cause a referral bias. However, the authors stated that they came up with the same relationship between flexed and extended wrist using only CTS cases from the population-based data. The risk of CTS was found to increase with the reported duration of activities with flexed wrist (RRs from 1.5 to 8.7, with increasing hours) or activities with extended wrist (RR from 1.4 to 5.4 with increasing hours) over the past 5 years, but not for working with a flexed or extended wrist in combination, or working with a pinched grasp. Given the period of recall for self-reported exposure (0–5 years), and no independent observation or attributes of exposure, these results must be interpreted with caution (meaning that within the limitations of the data and conclusions, when considered with other studies that have more stringent methods, the RRs seem consistent and supportive and do not offer alternate conclusions).

Armstrong and Chaffin's [1979] pilot study of female sewing machine operators with symptoms and/or signs for CTS compared to controls found that pinch force exertion (exposure measurements estimated from EMG, film analysis) was significantly associated (OR 2.0). Pinch force was a combination of factors—posture and forceful exertion. The authors reported that CTS-diagnosed subjects used deviated wrist postures more frequently than nondiseased, particularly during forceful exertions. What is unable to be answered due to the study design, was whether the deviated postures were necessitated due to symptoms and signs of CTS, or the deviated postures caused or exacerbated the symptoms and signs.

Stetson et al. [1993] found that "gripping greater than 6 pounds" per hand was a significant risk factor for median distal sensory dysfunction (an indicator of CTS) when the study population was divided into exposed and non-exposed groups. "Gripping greater than 6 pounds" is a variable which combines two work-related variables, posture and forceful exertion. As seen with other studies referenced above, the single work-related variable was not found to be associated with median nerve dysfunction, but the combination of variables was significant. Looking specifically at wrist deviation in the Stetson et al. [1993] study, the midpalm to wrist sensory amplitude was smaller in the group not exposed to wrist deviation

(p=0.04) compared to those exposed to wrist deviation (contrary to what was expected). Also, no significant differences were found in the mean measurements between nonexposed and exposed groups for use of pinch grip.

Tanaka et al. [1995] analysis of the Occupational Health Supplement of the NHIS population survey depended on self-reported CTS, self-reported exposure factors, and occupation of the respondent for analysis. Self-reported bending and twisting of the hand and wrist (OR 5.9) was found to be the strongest variable associated with "medically-called CTS" among recent workers, followed by race, gender, vibration and age (repetition and force were not included in the logistic models). Limitations of self-reported health outcome and exposure do not allow the conclusions of this study to stand alone; however, when examined with the other studies, it suggests a relationship between posture and CTS.

The two other studies which examined posture and its relationship to CTS did not focus on the hand and wrist. English et al. [1995] found a relationship between self-reported rotation of the shoulder and elevated arm and CTS, an OR of 1.8. Liss et al. [1995] found an OR of 3.7 for self-reported CTS comparing risk factors from dental hygienists to dental assistants, with self-reported percent of time the trunk was in a rotated position relative to the lower body as one of the factors.

Given these limitations of categorizing posture, three studies [Stetson et al. 1993; Loslever and Ranaivosoa 1993; Armstrong and Chaffin 1979] using different methods to measure posture and estimate force, found that the combination of significant force and posture was significantly related to CTS. Marras and Shoenmarklin [1993] also found posture to be significantly associated with CTS when comparing jobs where grip strength was three times greater than in the low risk jobs. In those studies which used self-reports for categorizing posture, the associations were also positive.

Temporal Relationship

There were no longitudinal studies which examined the relationship between extreme posture and CTS. Two cross-sectional studies that met the evaluation criteria addressed the association between posture and CTS. Silverstein et al. [1987] did not find a significant relationship between CTS and extreme posture, but exposure assessment was limited to representative workers; inter-individual variability limited the ability to identify actual relationships between postures and CTS. In the Stetson et al. [1993] study, the authors mentioned the limitations of interpretation of their posture results due to misclassification of workers. They extrapolated exposure data to non-observed workers, so individual variability in work methods and differing anthropometry are not accounted for. These limitations all influence outcome, and the conclusions must be interpreted with caution, and considered along with biomechanical and laboratory studies.

Coherence of Evidence

Flexed wrist postures may reduce the area of the carpal tunnel thus potentially increasing the pressure in the tunnel with a concomitant increase in the risk of CTS [Skie et al. 1990; Armstrong et al. 1991]. Marras and Shoenmarklin [1993] found that the variables of wrist flexion, extension, angular velocity, and wrist flexion, extension, angular acceleration discriminated between jobs with a high versus a low risk of having an upper extremity reportable injury (an OSHA recordable disorder due to repetitive trauma). The authors suggested that this result was due to high accelerations requiring high forces in tendons. Szabo and Chidgey [1989] showed that repetitive flexion and extension of the wrist created elevated pressures in the carpal tunnel compared to normal subjects, and that these pressures took longer to dissipate than in normal subjects. Observed repetitive passive flexion and extension appeared to "pump up" the carpal tunnel pressure; active motion of the wrist and fingers also had an effect over and above that of the passive motions tested. Laboratory studies demonstrate that carpal canal pressure is increased from less than 5mmHg to more than 30 mmHg during wrist flexion and extension [Gelberman et al. 1981].

Exposure-Response Relationship, CTS and Posture

Few studies address exposure-response relationship between CTS and extreme posture. deKrom et al. [1990] reported an increased risk of CTS with workers reporting increasing weekly hours of exposure to wrist flexion or extension (but not a combination of flexion/extension). Laboratory studies also support a dose-response relationship of increased carpal tunnel pressure due to increasing wrist deviation from neutral [Weiss et al. 1995] and pinch force [Rempel 1995].

In conclusion, there is **insufficient evidence** in the current epidemiologic literature to demonstrate that awkward postures alone are associated with CTS.

VIBRATION AND CTS

Definition of Vibration for CTS

We selected studies that addressed manual work involving vibrating power tools and CTS specifically.

Studies Meeting the Four Evaluation Criteria

Two studies examining the association between vibration and CTS fulfilled the four criteria [Chatterjee 1992; Silverstein et al. 1987]. Chatterjee et al. [1982] performed independent exposure assessment of the vibrating tools, and found the rock drillers to be exposed to vibration between the frequencies of 31.5 and 62 Hertz.

Silverstein et al. [1987] is discussed above. Silverstein [1987] had no quantitative measures of vibration, but observed exposure from videotapes and found all jobs with vibration exposure to be highly repetitive and mostly forceful jobs.

Studies Not Meeting the Evaluation Criteria

There are seven studies on Table 5a–4 that meet at least one of the four criteria.

In addition, there are 2 clinical case studies of vibration and CTS [Rothfleish and Sherman 1978; Lukas 1970] that were not controlled for confounders and not referenced in Table 5a–4. Rothfleisch and Sherman [1978] found an excess of power hand tool users among CTS patients. Lucas [1970] examined workers using vibrating hand tools including stone cutters, tunnelers, coal miners, forest workers and grinders (all with a mean of 14 years exposure to vibration) and found CTS in 21%. He found that the prevalence of CTS in some groups was as high as 33% (neither study had a referent group.)

Cannon et al. [1981] found that the self-reported use of vibrating tools, in combination with reported forceful and repetitive hand motions, was associated with a greater incidence of CTS than was repetitive motion alone.

Bovenzi's study in 1994 compared stone workers (145 quarry drillers and 425 stone carvers) exposed to hand-transmitted vibration to 258 polishers and machine operators who performed manual activity only not exposed to hand-transmitted vibration. CTS was assessed by a physician, and exposure was assessed through direct observation to vibrating tools and by interview. Vibration was also measured in a sample of tools.

Strength of Association: Vibration and CTS

Chatterjee et al. [1982] found a significant difference between rock drillers with symptoms and signs of CTS and the controls using the following NCS measurements: median motor latency, median sensory latency, median sensory amplitude, and median sensory duration, all at the $p<0.05$ level. Based on nerve conduction measurements, they also found an OR of 10.9 for rock drillers having abnormal NCS amplitudes in the median and ulnar nerves compared to controls. Bovenzi et al. [1991] found an OR of 21.3 for CTS based on symptoms and physical exam comparing vibration-exposed forestry operators using chain-saws to maintenance workers performing manual tasks. Bovenzi's study in 1994 found an OR of 0.43 for CTS defined by signs and symptoms, controlling for several confounders. In the Silverstein et al. [1987] study the crude OR for high force/high repetition jobs with vibration compared to high force/high repetition without vibration was 1.9, but not statistically significant. This suggested that there may have been confounding (the OR was not statistically significant) between high force/high repetition and vibration. Nilsson et al. [1990] found that platers operating tools such as grinders and chipping hammers had a CTS prevalence of 14% compared to 1.7% among office workers. Nathan et al. [1988] found a PR of 2.0 (95% CI 1.3–3.4) for slowing of nerve conduction velocity when grinders were compared to administrative and clerical workers. Cannon et al. [1981] found an OR of 7.0 for CTS with the use of vibrating hand tools, although there was a strong potential for confounding by hand or wrist posture and forceful exertion.

Temporal Relationship

There were no longitudinal studies which examined the relationship between vibration and CTS.

Consistency in Association

All studies on Table 5a–4 examining vibration and CTS found a significantly positive relationship between CTS and vibration exposure. Most studies had ORs greater than 3.0, so that results were less likely to be due to confounding.

Coherence of Evidence and Vibration

The mechanism by which vibration contributes to CTS and tendinitis development is not well understood, probably because vibration exposure is usually accompanied by exposure to forceful and repetitive movements. Muscles exposed to vibration exhibit a tonic vibration reflex that leads to increasing involuntary muscle contraction. Vibration has also been shown to produce short-term tactility impairments which can lead to an increase in the amount of force exerted during manipulative tasks. Vibration can also lead to mechanical abrasion of tendon sheaths. Neurological and circulatory disturbances probably occur independently by unrelated mechanisms. Vibration may directly injure the peripheral nerves, nerve endings, and mechanoreceptors, producing symptoms of numbness, tingling, pain, and loss of sensitivity. It has been found in rats that vibration has caused epineural edema in the sciatic nerve [Lundborg et al. 1987]. Vibration may also have direct effects on the digital arteries. The innermost layer of cells in the blood vessel walls appears especially susceptible to mechanical injury by vibration. If damaged, these vessels may become less sensitive to the actions of certain vasodilators that require an intact endothelium. The NIOSH Criteria Document on exposure to hand-arm vibration NIOSH [1989] quoted Taylor [1982] as follows: " It is not known whether vibration directly injures the peripheral nerves thereby causing numbness and subsequent sensory loss, or whether the para-anaesthesia of the hands is secondary to the vascular constriction of the blood vessels causing ischemia . . . in the nerve organs."

Exposure-Response Relationship, CTS and Vibration

In the studies examined, only dichotomous categorizations were made, so conclusions concerning an exposure-response relationship cannot be drawn. However, we can see significantly contrasting rates of CTS between high and low exposure groups. Wieslander et al. [1989] found that based on exposure information obtained from telephone interviews, CTS surgery was significantly associated with vibration exposure. Exposure for 1–20 years gave an OR of 2.7, more than 20 years gave an OR of 4.8.

Conclusion

In conclusion, there is **evidence** supporting

an association between exposure to vibration and CTS.

CONFOUNDING AND CTS

It is clear that CTS has several non-occupational causes. When examining the relationship of occupational factors to CTS, it is important to take into account the effects of these individual factors; that is, to control for their confounding or modifying effects. Studies that fail to control for the influence of individual factors may either mask or amplify the effects of work-related factors. Most of the epidemiologic studies of CTS that address work factors also take into account potential confounders.

Almost all of the studies reviewed controlled for the effects of age in their analysis [Chiang et al. 1990, 1993; Stetson et al. 1993; Silverstein et al. 1987; Wieslander et al. 1989; Baron et al. 1991; Tanaka et al. 1995, In Press; McCormack et al. 1990]. Likewise, most studies included gender in their analysis, either by stratifying [Schottland et al. 1991; Chiang et al. 1993], by selection of single gender study groups [Morganstern et al. 1991; Punnett et al. 1985] or by including the variable in the logistic regression model [Silverstein et al. 1987; Stetson et al. 1991; Baron et al. 1991]. Through selection of the study population and exclusion of those with metabolic diseases, most studies were able to eliminate the effects from these conditions. Other studies did control for systemic disease [Chiang et al. 1993; Baron et al. 1991]. Anthropometric factors have also been addressed in several studies [Stetson et al. 1993; Nathan et al. 1997; 1992b; Werner et al. 1997]. As more is learned about confounding, more variables tend to be addressed in more recent studies (smoking, caffeine, alcohol, hobbies). In those older studies which may not have controlled for multiple confounders, it is unlikely that they are highly correlated with exposure, especially those with ORs above 3.0. When examining those studies that have good exposure assessment, widely contrasting levels of exposure, and that control for multiple confounders, the evidence supports a positive association between occupational factors and CTS.

CONCLUSIONS

There are over 30 epidemiologic studies which have examined workplace factors and their relationship to CTS. These studies generally compared workers in jobs with higher levels of exposure to workers with lower levels of exposure, following observation or measurement of job characteristics. Using epidemiologic criteria to examine these studies, and taking into account issues of confounding, bias, and strengths and limitations of the studies, we conclude the following:

There is **evidence** for a positive association between highly repetitive work and CTS. Studies that based exposure assessment on quantitative or semiquantitative data tended to show a stronger relationship for CTS and repetition. The higher estimates of RR were found when contrasting highly repetitive jobs to low repetitive jobs, and when repetition is in combination with high levels of forceful exertion. There is **evidence** for a positive association between force and CTS based on currently available epidemiologic data. There is **insufficient evidence** for a positive association between posture and CTS. There is **evidence** for a positive association between jobs with exposure to vibration and CTS. There is **strong evidence** for a relationship between exposure to a combination of risk factors (e.g., force and repetition, force and posture) and CTS. Ten studies allowed a comparison of the effect of individual versus combined work risk factors [Chiang et al. 1990, 1993; Moore and Garg 1994; Nathan et al. 1988, 1992a; Silverstein et al. 1987; Schottland et al. 1991; McCormack et al. 1990; Stetson et al. 1993; Tanaka et al. [In Press]. Nine of these studies demonstrated higher estimates of RR when exposure was to a combination of risk factors, compared to the effect of individual risk factors. Based on the epidemiologic studies reviewed above, especially those with quantitative evaluation of the risk factors, the evidence is clear that exposure to a combination of job factors studied (repetition, force, posture, etc.) increases the risk for CTS. This is consistent with the evidence that is found in the biomechanical, physiologic, and psychosocial literature.

Table 5a-1. Epidemiologic criteria used to examine studies of carpal tunnel syndrome (CTS) associated with repetition

Study (first author and year)	Risk indicator (OR, PRR, IR or *p*-value)[*,†]	Participation rate ≥70%	Physical examination, and/or nerve conduction studies	Investigator blinded to case and/or exposure status	Basis for assessing hand exposure to repetition
Met all four criteria:					
Chiang 1990	1.87[†]	Yes	Yes	Yes	Observation or measurements
Chiang 1993	1.1	Yes	Yes	Yes	Observation or measurements
Moore 1994	2.8	Yes	Yes	Yes	Observation or measurements
Osorio 1994	6.7	Yes	Yes	Yes	Observation or measurements
Silverstein 1987	5.5[†]	Yes	Yes	Yes	Observation or measurements
Met at least one criterion:					
Barnhart 1991	1.9–4.0[†]	No	Yes	Yes	Observation or measurements
Baron 1991	3.7	No	Yes	Yes	Observation or measurements
Cannon 1981	2.1	NR[‡]	Yes	NR	Job titles or self-reports
English 1995	0.4	Yes	Yes	Yes	Job titles or self-reports
Feldman 1987	2.26[†]	Yes	No	NR	Observation or measurements
McCormack 1990	0.5	Yes	Yes	NR	Job titles or self-reports
Morgenstern 1991	1.88	Yes	No	No	Job titles or self-reports
Nathan 1988	1.0	NR	Yes	NR	Observation or measurements
Nathan 1992a	1.0	No	Yes	NR	Observation or measurements
Punnett 1985	2.7[†]	No	Yes	NR	Job titles or self-reports
Schottland 1991	2.86[†], 1.87	NR	Yes	NR	Job titles or self-reports
Stetson 1993	NR	Yes	Yes	NR	Observation or measurements
Weislander 1989	2.7[†]	Yes	Yes	No	Job titles or self-reports
Met none of the criteria:					
Liss 1995	5.2 3.7[†]	No	No	No	Job titles or self-reports

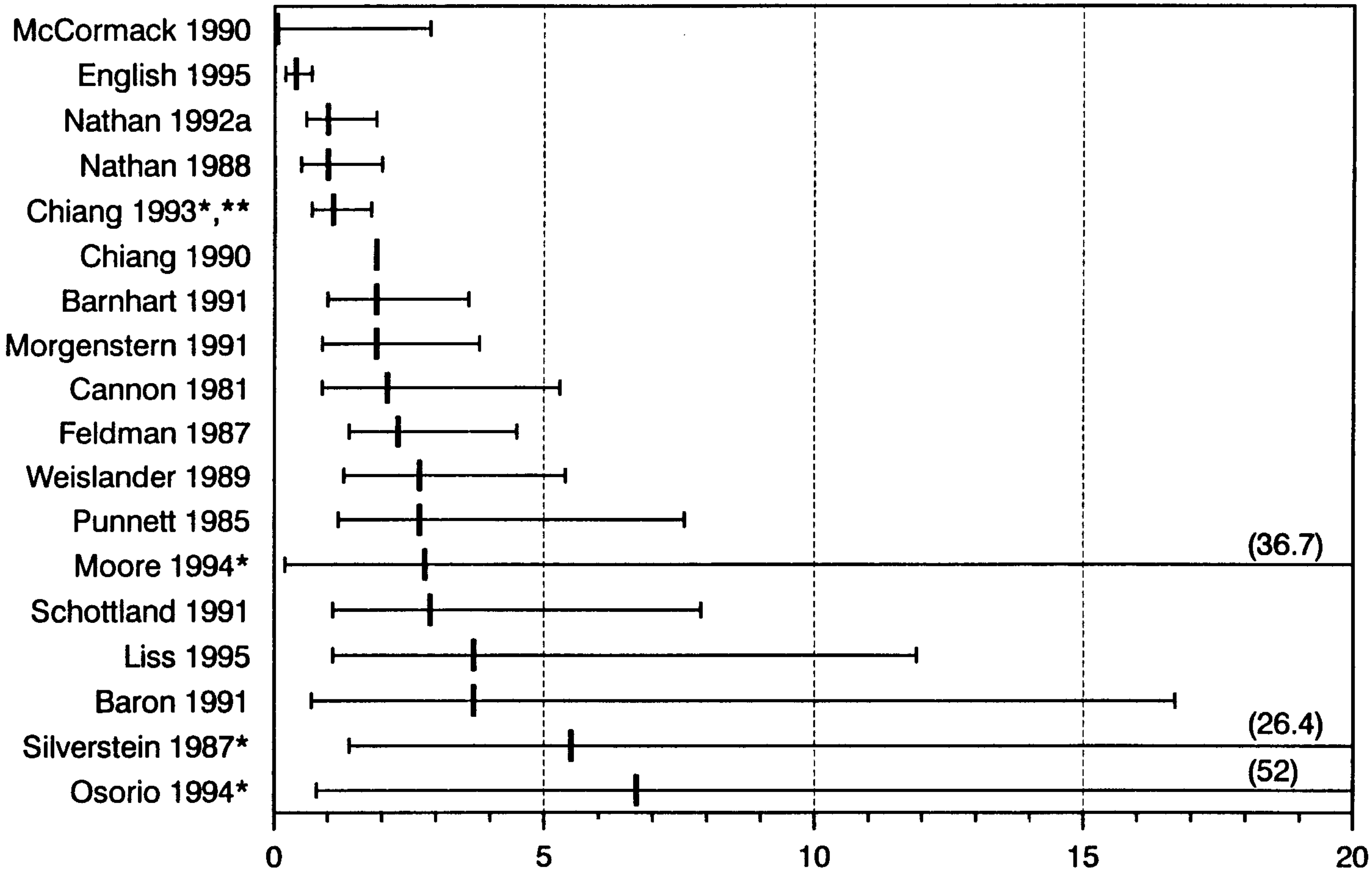
[*]Some risk indicators are based on a combination of risk factors—not on repetition alone (i.e., repetition plus force, posture, or vibration). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

[†]Indicates statistical significance.

[‡]Not reported.

Figure 5a-1. **Risk Indicator for "Repetition" and Carpal Tunnel Syndrome**

(Odds Ratios and Confidence Intervals)



* Studies which met all four criteria.

**Significant risk indicator reported without confidence limits.

Note: Two studies indicated statistically significant associations without reporting odds ratios. See Table 5a-1.

Table 5a-2. Epidemiologic criteria used to examine studies of carpal tunnel syndrome (CTS) associated with force

Study (first author and year)	Risk indicator (OR, PRR, IR, or *p*-value)[*,†]	Participatio n rate $70%	Physical examination, and/or nerve conduction studies	Investigato r blinded to case and/or exposure status	Basis for assessing hand exposure to force
Met all four criteria:					
Chiang 1993	1.8[†]	Yes	Yes	Yes	Observation or measurements
Moore 1994	2.8	Yes	Yes	Yes	Observation or measurements
Osorio 1994	6.7	Yes	Yes	Yes	Observation or measurements
Silverstein 1987	15.5[†]	Yes	Yes	Yes	Observation or measurements
Met at least one criterion:					
Armstrong 1979	2.0[†]	NR[‡]	No	No	Observation or measurements
Baron 1991	3.7	No	Yes	Yes	Observation or measurements
McCormack 1990	0.4-0.9	Yes	Yes	NR	Job titles or self-reports
Nathan 1988	1.7-2.0[†]	NR	Yes	NR	Observation or measurements
Nathan 1992a	1.0, 1.4[†], 1.6	No	Yes	NR	Observation or measurements
Punnett 1985	2.7[†]	No	Yes	NR	Job titles or self-reports
Stetson 1993	NR[†]	Yes	Yes	NR	Observation or measurements

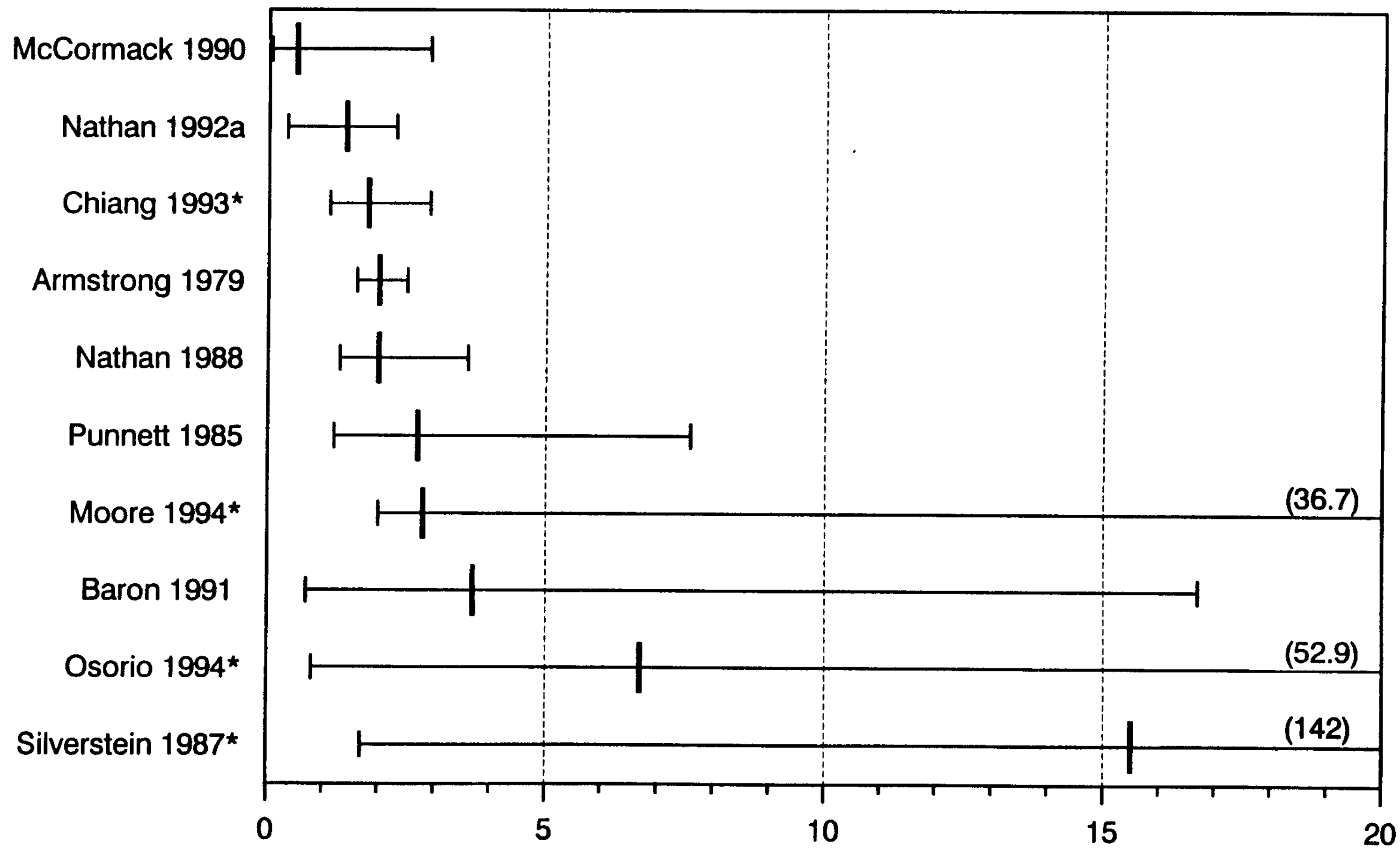
[*]Some risk indicators are based on a combination of risk factors—not on force alone (i.e., force plus repetition, posture, or vibration). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

[†]Indicates statistical significance. If combined with NR, a significant association was reported without a numerical value.

[‡]Not reported.

Figure 5a-2. **Risk Indicator for "Force" and Carpal Tunnel Syndrome**

(Odds Ratios and Confidence Intervals)



* Studies which met all four criteria.

Note: Some studies indicate statistical significance without a risk indicator or reported a statistically significant association without a risk indicator. See Table 5a-2.

Table 5a-3. Epidemiologic criteria used to examine studies of carpal tunnel syndrome (CTS) associated with posture

Study (first author and year)	Risk indicator (OR, PRR, IR, or *p*-value)*,†	Participation rate $70%	Physical examination, and/or nerve conduction studies	Investigator blinded to case and/or exposure status	Basis for assessing hand exposure to posture
Met all four criteria:					
Moore 1994	2.8	Yes	Yes	Yes	Observation or measurements
Silverstein 1987	NR‡	Yes	Yes	Yes	Observation or measurements
Met at least one criterion:					
Armstrong 1979	2.0†	NR	No	No	Observation or measurements
deKrom 1990	5.4†	Yes	Yes	NR	Job titles or self-reports
English 1995	1.8†	Yes	Yes	Yes	Job titles or self-reports
Stetson 1993	NR†	Yes	Yes	NR	Observation or measurements
Tanaka 1995	5.9†	Yes	No	No	Job titles or self-reports
Met none of the criteria:					
Liss 1995	3.7†	No	No	No	Job titles or self-reports

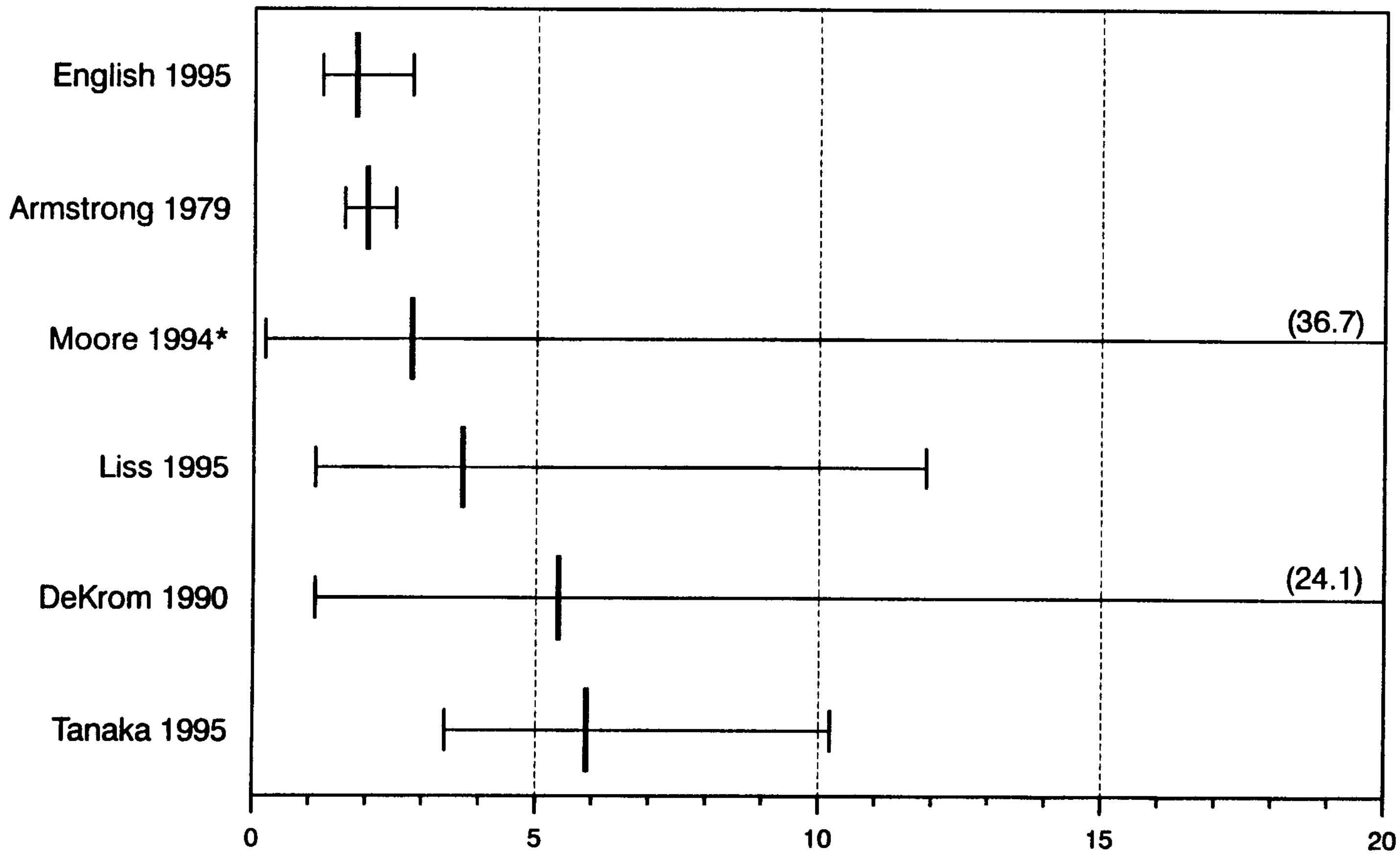
*Some risk indicators are based on a combination of risk factors—not on posture alone (i.e., posture plus repetition, force, or vibration). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

†Indicates statistical significance. If combined with NR, a significant association was reported without a numerical value.

‡Not reported.

Figure 5a-3. **Risk Indicator for "Posture" and Carpal Tunnel Syndrome**

(Odds Ratios and Confidence Intervals)



* Studies which met all four criteria.

Note: One study indicated statistically significant association without reporting odds ratios. See Table 5a-3.

Table 5a-4. Epidemiologic criteria used to examine studies of carpal tunnel syndrome (CTS) associated with vibration

Study (first author and year)	Risk indicator (OR, PRR, IR, or p-value)[*,†]	Participation rate $70%	Physical examination, and/or nerve conduction studies	Investigator blinded to case and/or exposure status	Basis for assessing hand exposure to vibration
Met all four criteria:					
Chatterjee 1992	10.9[†]	Yes	Yes	Yes	Observation or measurements
Silverstein 1987	5.3[†]	Yes	Yes	Yes	Observation or measurements
Met at least one criterion:					
Bovenzi 1991	21.3[†]	NR[‡]	Yes	Yes	Observation or measurements
Bovenzi 1994	3.4[†]	Yes	Yes	No	Observation or measurements
Cannon 1981	7.0[†]	NR	Yes	NR	Job titles or self-reports
Färkkilä 1988	NR[†]	NR	Yes	NR	Job titles or self-reports
Koskimies 1990	NR[†]	NR	Yes	No	Observation or measurements
Tanaka *In Press*	1.8[†]	Yes	No	No	Job titles or self-reports
Weislander 1989	3.3[†]	Yes	Yes	No	Job titles or self-reports

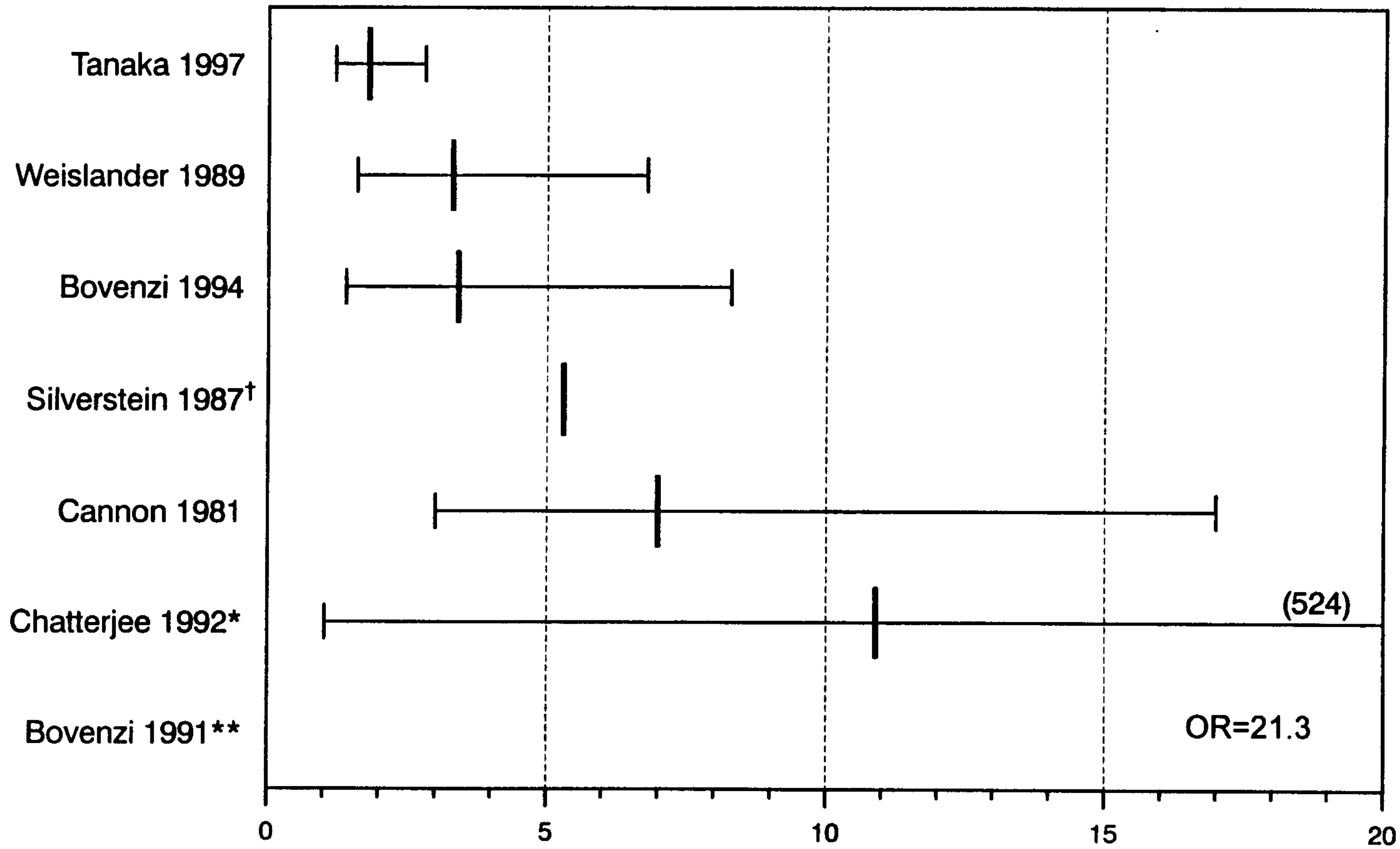
[*]Some risk indicators are based on a combination of risk factors—not on vibration alone (i.e., vibration plus repetition, posture, or force). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

[†]Indicates statistical significance. If combined with NR, a significant association was reported without a numerical value.

[‡]Not reported.

Figure 5a-4. **Risk Indicator for "Vibration" and Carpal Tunnel Syndrome**

(Odds Ratios and Confidence Intervals)



* Studies which met all four criteria.
**Significant risk indicator reported without confidence limits.
† Studies which met all four criteria and had significant risk indicator reported without confidence limits.
Note: Two studies indicated statistically significant associations without reporting odds ratios. See Table 5a-4.

Table 5a–5. Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Armstrong and Chaffin 1979	Case-control	18 female sewing machine operators with CTS histories compared to 18 female sewing machine operators without CTS histories.	Outcome: CTS defined as history of symptoms, surgical decompression of the median nerve, positive Phalen's test, or thenar atrophy. Exposure: Hand/wrist postures and estimation of forearm flexor force in various wrist and hand postures assessed by film analysis and EMG.	õ	õ	For pinch force exertion: 2.0 For hand force: 1.05	1.6-2.5 1.0-1.2	Participation rate: Not reported. All cases of CTS diagnosed prior to study in working sewing machine operators, may cause referral bias in estimating role of workload. Subjects excluded if history of fractures, metabolic or soft tissue disease. No association found between hand size or shape and CTS. CTS diagnosed subjects used deviated wrist more frequently than non-diseased, particularly during forceful exertions.

(Continued)

Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Barnhart et al. 1991	Cross-sectional	Ski manufacturing workers: 106 with repetitive jobs compared to 67 with non-repetitive jobs.	Outcome: CTS determined by: (1) Case 1: Electro-diagnosis of median-ulnar difference (latency on response time);	Case 1: 34%	19%	1.9	1.0-3.6	Participation rate: 70% (repetitive jobs), 64% (non-repetitive jobs).
			(2) Case 2: Either Tinel's or Phalen's test and electro-diagnosis;	Case 2: 15.4%	3.1%	3.95	1.0-15.8	Examiner blinded to subject's job status but clothing may have biased observations.
			(3) Case 3: Ever having symptoms of hand pain, tingling, numbness, or nocturnal hand pain and Tinel's or Phalen's test and electro-diagnosis. Exposure: Jobs classified as repetitive and non-repetitive. Repetitive jobs entailed repeated or sustained flexion, extension, or ulnar deviation of the wrist by 45E, radial deviation by 30E, or pinch grip (determined by observation).	Case 3: 32.5%	18.2%	1.6	0.8-3.2	Controlled for age and gender. Found for both right and left hand of those with repetitive jobs; mean difference between distal sensory latencies of median and ulnar nerves were primarily due to a shorter mean sensory latency of the ulnar nerve. There was no difference in median nerve distal sensory latencies between groups. Hormonal status, systemic disease included in questionnaire. Diabetes significantly more frequent in those with CTS than without (*p*=0.01).

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Baron et al. 1991	Cross-sectional	119 female grocery checkers vs. 56 other female grocery store employees (comparison group).	Outcome: CTS case defined as having moderate to severe symptoms of pain, stiffness, numbness, tingling. Symptoms begun after employment in the current job; lasted > one week or occurred > once a month during the past year; no history of acute injury to part of body in question and a positive physical exam of either Phalen's or Tinel's test. Exposure: Based on job category, estimates of repetitive, average, and peak forces based on observed and videotaped postures, weight of scanned items, and subjective assessment of exertion. Exposure level in checkers: Average forces: Low Peak force: Medium Repetition: Medium Exposure level in referents: Average force: Medium Peak force: Medium to low Repetition: Medium.	11%	4%	3.7	0.7-16.7	Participation rate: 85% checkers; 55% non-checkers in field study. Following telephone survey 91% checkers and 85% non-checkers. Adjusted for duration of work. Total repetitions/hr ranged from 1,432 to 1,782 for right hand and 882 to 1,260 for left hand. Multiple awkward postures of all upper extremities recorded but not analyzed in models. Examiners blinded to worker's job and health status. Controlled for duration of work, hobbies.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Bovenzi et al. 1991	Cross-sectional	65 vibration-exposed forestry operators using chain-saws compared to referents composed of 31 maintenance workers (electricians, mechanics, and painters).	Outcome: CTS cases defined as having symptoms of pain, numbness, or tingling in the median nerve distribution, and physical exam findings of Tinel's or Phalen's test, diminished sensitivity to touch or pain in 3½ fingers on radial side, weakness in pinching or gripping. Exposure: Direct observation of awkward postures, manual forces, and repetitiveness evaluated via checklist. The focus of the study was to compare vibration-exposed workers to controls doing manual work. Vibration measured from two chain-saws. Vibration exposure for each worker assessed in terms of 4-hr energy-equivalent frequency-weighted acceleration according to ISO 5349.	38.4%	3.2%	21.3 (adjusted)	p=0.002	Participation rate: Not reported. Examiners blinded to case status. Controlled for age and ponderal index (height and weight variable). Metabolic disease also considered. Controls also found to have several risk factors for MSDs at work—static arm and hand overload, overhead work, stressful postures, non-vibrating hand-tool use. Controls had a greater proportion of time in work cycles shorter than 30 sec than forestry workers. Chain saw operators worked outdoors and were exposed to lower temperatures than maintenance workers.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	Referent group	RR, OR, or PRR	95% CI	Comments
Bovenzi and the Italian Group 1994	Cross-sectional	Case group: Stone workers employed in 9 districts in Northern and Central Italy; 145 quarry drillers and 425 stone carvers exposed to vibration. Referent group: Polishers and machine operators (n=258) who performed manual activity but were not exposed to hand-transmitted vibration. All stone workers employed in 6 districts participated in the survey (n=578, 69.8%), whereas, in the three other districts they were selected on basis of random sampling of the quarries and mills in the geographic areas (n=250, 30.2%).	Outcome: CTS assessed by physician assessment. CTS defined as symptoms, (1) parathesias, numbness, or pain in median nerve distribution; (2) nocturnal exacerbation of symptoms and positive Tinel's or Phalen's test. Exposure: Direct observation of vibrating tools assessed by interview. Vibration measured in a sample of tools.	8.8%	2.3%	3.4	1.4-8.3	Participation rate: 100%. "All the active stone workers participated in the study, so self-selection was not a source of bias." Physician administered questionnaires containing work history and examinations, so unlikely to be blinded to case status. Adjusted for age, smoking, alcohol consumption, and upper limb injuries. Leisure activities and systemic diseases included in questionnaire. Univariate analysis showed no association between systemic diseases and vibration so were not criteria for exclusion. Dose-response for CTS and lifetime vibration exposure not significant.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	Referent group	RR, OR, or PRR	95% CI	Comments
Cannon et al. 1981	Case-control	Aircraft engine workers at 4 plants: 30 CTS cases identified through worker's compensation claims and medical department records during a 2-year period compared to 90 controls from the same plant, 16 workers receiving compensation benefits for treatment of CTS, and 14 cases who had not received compensation benefits. Three controls randomly chosen from the same plant for each CTS case.	Outcome: CTS cases identified through worker's compensation claims and medical department records during a 2-year period. Exposure: Based on job category, years on the job, identified through record review and interviews. Exposure to vibrating tools, repetitive motion. Buffing, grinding, and hand tools were measured with an accelerometer and found to be in the range of 10 to 60 Hz.	Õ	Õ	For vibrating hand tool use: 7.0 For repetitive motion tasks: 2.1 History of gynecologic surgery: 3.7 Years on the job: 0.9	3.0-17 0.9-5.3 1.7-8.1 0.8-1.0	Participation rate: Participation rate unable to be calculated from data presented. 30 cases identified through record review of 20,000 workers. Cases and controls on gender. Controlled for gynecologic surgery, race, diabetic history, years on the job, use of low-frequency vibrating tools. Information obtained through self-administered questionnaires and personal interviews on cases and controls on age, sex, race, weight, occupation, years employed, worker compensation status, history of metabolic disease, hormonal status of females, history of gynecologic surgery. Number of years employed significantly different among cases (5.5 years) and controls (11.7 years). Range of years employed among cases included 0.1 year to 28 years.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	Referent group	RR, OR, or PRR	95% CI	Comments
Chatterjee et al. 1982	Case-control	16 rock drillers compared with 15 controls.	Outcome: CTS was determined by symptoms from questionnaire and interview by medical investigator, clinical exams carried out blindly, and nerve conduction studies. For Table 5-7, CTS based solely on NCS results; Table 5-9 based on symptoms and NCS. Exposure: To vibration carried out by measurement of vibration spectra of the rock drills and observation of jobs. Exposed group were those miners who regularly used rock-drills in the fluorspar mines or other miners using similar rock-drills. Exposure varied from 18 months to 25 years (mean 10 years). The rock drillers were exposed to vibration level in excess of the damage level criterion between the frequencies of 31.5 and 62 Hz.	44%	7%	Abnormal amplitudes of digital-action potentials from fingers supplied by the median and ulnar nerves; the OR in vibration exposed vs. controls: OR=10.89	1.02-524	Participation rate: 93%. Examiners blinded to case status. Groups standardized for age and gender. Exclusionary criteria: History of constitutional white finger, secondary causes of Raynaud's phenomenon, > one laceration or fracture in the hands or digits, severe or complicated injury involving nerve or blood vessels or significant surgical operation, history of exposure to vibration from tools other than rock drills. Significant differences found between controls and vibration group for symptoms of numbness and tingling: median motor latency; median sensory latency; median sensory amplitude; median sensory duration. All at the $p < 0.05$ level. Skin temperature controlled for in NCVs.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Chiang et al. 1990	Cross-sectional	207 active workers from 2 frozen food plants divided into 3 groups: (1) low-cold, low-repetition (comparison group, mainly office staff and technicians, n=49), (2) low-cold, high-repetition (non-frozen food packers, n=37), (3) high-cold, high-repetition (frozen food packers, n=121).	Outcome: CTS defined as symptoms of numbness, pain, tingling in the fingers innervated by the median nerve, onset since work in current job, no relationship to systemic disease or injury and physical exam of Tinel's test or Phalen's sign. Nerve conduction testing was performed on motor and sensory nerves of both upper limbs. If subject had abnormal results and symptoms and physical exam findings, was considered CTS. If no symptoms, considered as subclinical CTS. Exposure: Job analyses conducted by industrial hygienist, to cold and repetition assessed by observation. Highly repetitive jobs had cycle times <30 sec. >50% of cycle time cold exposure was defined as whether the job required hands to be locally exposed to cold. The mean skin temperature of their hands was in the range of 26 to 28EC, even with wearing gloves.	Group 2: 40.5% clinical plus 8.1% sub-clinical Group 3: 37.2% clinical plus 22.3% sub-clinical	Group 1: 4% clinical plus 2% sub-clinical	Group 2 vs. Group 1: OR=8.28 Group 3 vs. Group 1: OR=11.66 Logistic Regression Model: Cold: OR=1.85 (*p*<0.22) Repetitiveness: OR=1.87 (*p*<0.018) Cold x Repetitive-ness: OR=1.77 (*p*<0.03)	1.18-58.3 2.92-46.6	Participation rate: Not specifically mentioned, however, paper states that “in order to prevent selective bias, all of the employees in the factories were observed initially.” Examiners blinded to exposure status and medical history. Controlled for age, sex, and length of employment. Interaction terms tested. Excluded subjects with diabetes, thyroid function disorders, history of forearm fracture, unspecified polyneuropathy, rheumatoid arthritis. Workers in cold groups wore gloves and exerted higher forces than workers in non-cold groups. Force was not evaluated in this study. Confounding is possible according to authors. CTS was independent of age and length of employment. Authors considered this to be due to healthy worker effect. OR for group 1 vs. group 2 is 8.3 (1.2-58.3) when adjusted for sex but 2.2 (0.2-21.1) when adjusted for sex, age, and length of employment suggesting survival bias.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Chiang et al. 1993	Cross-sectional	207 fish processing workers divided in 3 groups: (1) low-force, low-repetition (comparison group, n=61); (2) high-force or high-repetition (n=118); (3) high-force and high-repetition (n=28).	Outcome: CTS defined as having symptoms of numbness, pain, or tingling in the fingers innervated by the median nerve, onset after job began, and no evidence of systemic disease or injury and physical exam findings of positive Tinel's sign or Phalen's test. Exposure: Assessed by observation and recording of tasks and biomechanical movements of 3 workers, each representing 1 of 3 study groups. Highly repetitive jobs with cycle time <30 sec or >50% of cycle time performing the same fundamental cycles. Hand force from EMG recordings of forearm flexor muscles. Classification of workers into 3 groups according to the ergonomic risks of the shoulders and upper limbs: Group 1: low-repetition and low-force; Group 2: high-repetition and high-force; Group 3: high-repetition or high-force.	Group 2 (Male): 6.9% Group 2 (Female): 18.0% Group 3 (Male): 0.0% Group 3 (Female): 36.4%	Group 1 (Male): 3.1% Group 1 (Female): 13.8%	2 vs. 1 (male): OR= 2.2 2 vs. 1 (female): OR=1.3 3 vs. 1 (male): õ 3 vs. 1 (female): OR=2.6 Repetition: OR=1.1 Force: OR=1.8 Repetition and force: OR=1.1 Male vs. female: OR=2.6	0.2-22.0 0.5-3.5 õ 1.0-7.3 0.7-1.8 1.1-2.9 0.7-1.8 1.3-5.2	Participation rate: Paper stated that all of the workers who entered the fish-processing industry before June 1990 and were employed there full-time were part of the cohort. Workers examined in random sequence to prevent observer bias; examiners blinded to case status. Analysis controlled for age, stratified by gender. Contraceptive use (females): significant (OR=2.0, 95% CI 1.2 to 5.4); tubal ligation not significant. Workers with hypertension, diabetes, history of traumatic injuries to upper limbs, arthritis, collagen diseases excluded from study group. No significant age difference in exposure groups. Physician-observed cases about ½ the prevalence of symptoms of elbow pain (9.8 vs. 18.0; 15.3 vs. 19.5; 35.7 vs. 17.9). Dose-response for symptoms both in the hand and in the wrist (*p*<0.03) and physician-observed CTS (*p*<0.015). Age, gender, repetitiveness, forceful movement of upper limbs and interaction of repetitiveness and forceful movement calculated in logistic regression. Significant trend for duration of employment in <12 months but not 12 to 60 months or >60 months.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
deKrom et al. 1990	Nested case control	28 CTS cases from a community sample and 128 CTS cases from a hospital (total n=156) compared to community non-cases (n=473). Participants blinded to aim of study—told it was about "general health."	Outcome: Tingling pain and numbness in median distribution, frequency $2/week, awakened at night and nerve conduction studies. Motor latency < 4.5 months, different median to ulnar DSL < 4.0 months, controlled for temperature. CTS diagnosed by clinical history and neurophysiological tests. Exposure: Awkward hand/finger postures and pinch grasps assessed by questionnaire: Self-reported information about duration of exposure (hr/wk) to flexed wrist, extended wrist, extended and flexed wrist combined, pinched grasp. Typing hr categorized as 0, 1 to 7, 8 to 19, 20 to 40 hr/wk of exposure 0 to 5 years ago, responses truncated at 40 hr/wk.	5.6% prevalence in the general population (28 cases from 501 subject community sample)	Õ	For work: 20 to 40 hr/wk with flexed wrist: OR=8.7 For work: 20 to 40 hr/wk with extended wrist: OR= 5.4	3.124.1 1.127.4	Participation rate: 70% response rate obtained for both hospital and community samples. Controlled for age, weight, slimming courses, gender, and checked for interactions. Cases seeking medical care may cause referral bias in estimating etiologic role of work-load. However, authors came up with same relationship between flexed and extended wrist using only CTS cases from population-based data. The associations from this study are based on very small sample sizes. >64% of cases reported 0 hr/wk to each of the exposures. In random sample, age, and sex stratified, included twice as many females as males. No significant relationship between pinch grasp or typing. Dose-response found for duration of activities with flexed or extended wrist statistically significant; dose-response relationship for both present but not statistically significant. Typing hr not significant but very small numbers (<5 in comparison groups); may have been unable to detect a difference. Females with hysterectomy without oophorectomy significantly increased risk, PRR=2.0 (1 to 3.6), compared to females not operated on; increase may be detection bias. Wrist fractures, thyroid disease, rheumatism, and diabetes not significant for CTS. Varicosis significant risk for males 12.0 (3.6-40.1). Oral contraceptives not significantly associated with CTS.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
English et al. 1995	Case-control	Cases: CTS patients (n=171) ages 16 to 65 years from orthopedic clinics. Controls: (n=996) 558 males and 438 females attending the same clinics diagnosed with conditions other than diseases of the upper limb, cervical, or thoracic spine; ages 16 to 65 years.	Outcome: CTS based on agreed criteria diagnosed by orthopedic surgeons using common diagnostic criteria (not specified). Exposure: Based on self-reported risk factors at work: questions addressed: awkward postures, grip types, wrist motions, lifting, shoulder postures, static postures, etc. and job category.	Õ	Õ	Rotating shoulder with elevated arm and CTS: OR=1.8 Repeated finger tapping and CTS: OR=0.4	1.2-2.8 0.2-0.7	Participation rate: 96%. Due to design of study (cases selected by diagnoses), blinding of examiners not an issue. Adjusted for height, weight, and gender. Significant negative association with height and presentation at the clinic as a result of an accident and CTS. A significantly positive association with height. Included “frequency of movements” in regression analysis.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Färkkilä et al. 1988	Cross-sectional	79 chain saw users randomly selected from 186 forestry workers with >500 hr of sawing/year.	Outcome: CTS based on nerve conduction studies, motor and sensory conduction velocity, distal and proximal latencies, Tinel's and Phalen's tests and subjective symptoms. Exposure: Chain saw vibration not measured. Duration of chain saw use determined by interview.	26%	Õ	Significant correlation between numbness in the hands (r=0.38, *p*<0.05) and CTS and muscle fatigue (r=0.47, *p*<0.05) and CTS.	Õ	Participation rate: 100% of professional forestry workers. Significant correlation between CTS and HAVs found. Randomly selected from EMG out of 186. Alcohol consumption did not correlate with numbness in the hands or arms (r=0.14, p=NS) or sensory disturbances. Only motor nerve recordings were analyzed for this study.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Feldman et al. 1987	Cross-sectional for symptom survey Pro-spective for nerve con-duction studies	586 electronics workers at a manufacturing firm with 700 employees.	Outcome: Based on questionnaire survey and in some an abbreviated neurologic examination that involved tests of hand sensation, finger grip, and strength of thenar muscles. Tinel's and Phalen's done. "Standard nerve conduction" of left and right median nerves. Exposure: Two subjects randomly selected for biomechanical analyses from each of four high-risk areas, determined from questionnaire and walk-through observations of tasks involving repetitive flexion, extension, pinching, and deviated wrist postures. Videotaping and electromyography done. Highly repetitive job task defined as <30 sec cycle or >50% of cycle performing the fundamental cycle. Wrist posture characterized in terms of flexion and extension: >45 flexed, 15 to 45 flexion, neutral, 15 to 45 extension, and >45 extension and deviation. Hand posture characterized by 6 types of grip. No quantitative measures of vibration were obtained.	Wrist tingling and numbness: 18%	Wrist tingling and numbness: 8.7%	Numbness and tingling in fingers: OR=2.26 High-risk vs. low-risk jobs: *p*<0.005	1.4-4.46	Participation rate: 84%. Examiners blinded to case and exposure status: Not stated. Analysis not controlled for confounders. Questionnaire obtained data on past medical history, exposure to neurotoxins, cigarettes, hobbies, and symptoms. For nerve conduction testing, the temperature of limbs was monitored and controlled for. More females were in high-risk areas and jobs than males. There were no workers >60 years old in high-risk group. There were 34 workers >60 years in comparison groups. Rheumatoid arthritis more prominent in low-risk group (8.2%) than high-risk (2.4%) group. Nerve conduction in high-risk workers performed year 1 and year 2. Right sensory amplitude abnormal (<8µV) in 22% of workers at year 1 and 35.5% at year 2. Left sensory amplitude abnormal in 16.7% and 29% at year 2. Most apparent changes (increases) seen in bilateral sensory velocities and motor latencies (abnormal >4.5). Right motor latency abnormal in 8% at year 1 and 11% in year 2. Left motor latency abnormal in 2% in year 1 and 23% at year 2. Authors offered parameters for staging CTS in high-risk subjects (0 to 4 stages).

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Franklin et al. 1991	Retro-spective cohort: from 1984 to 1988	Workers in Washington State (n=1.3 million full-time workers in 1988). Worker's compensation data for Washington State, using compensable (time loss) and non-compensable claims for January 1984 to December 1988.	Outcome: Assessed using workers' compensation claims for CTS using ICD codes 354.0 and 354.1. Incident claim was the first appearance of a paid bill for claimant with a physician diagnosis. Algorithm was developed to identify unique claimants which removed multiple claims. Exposure: Not measured. Workers in the same industrial classification assumed to share similar workplace exposures.	25.7 claims/ 1,000 FTEs (oyster and crab packers) 23.9 claims/ 1,000 FTEs (meat and poultry workers)	1.74 claims/ 1,000 FTEs (industry wide rate)	14.8 (oyster and crab packers) 13.8 (meat and poultry workers)	11.2- 19.5 11.6- 16.4	Participation rate: This is a records review so it does not apply. Among claimants, the female-to-male ratio was 1.2:1. Mean age of claimants was 37.4. Diagnosis and data entry errors comprised 25% of CTS surgery claims—cases were not coded as CTS. 82% of claims were true cases of CTS.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Koskimies et al. 1990	Cross-sectional	217 forestry workers who used chain saw >500 hr during previous 3 years.	Outcome: 125 randomly selected for EMG of sensory and motor nerves both hands. CTS diagnosis based on symptoms, exclusion of other conditions, results of Phalen's and Tinel's test, and findings in sensory and motor nerve EMG. Exposure: Number of years of vibration exposure (only workers who had 500 hr during previous 3 years were included.	Active vibration: 5% white finger CTS: 20%		Alcohol consumption and CTS cases r=0.15 Vibration exposure time and motor NCV in median nerve of right hand: r=-0.27 but not left hand: r=-0.12 Exposure time with both motor NCV in ulnar nerve of right hand r=-0.26 and left hand r=-0.39. Distal latencies in median nerve and exposure in right hand r=0.17; left hand r=0.21. Numbness and sensory NCS of median nerve; right hand r=0.679; left hand r=0.53.	*p*=NS *p*=0.01 *p*=NS *p*=0.05 *p*<0.001 *p*=0.05 *p*=0.05 *p*<0.001 *p*<0.01	Participation rate: Not reported. Examiners may not have been blinded to exposure status because of design of study. No comparison group because study was part of longitudinal study of workers followed since 1972. Most of 25 CTS workers had mild symptoms at work despite severe reduction of sensory NCS of median nerve. Males with primary Raynaud's disease, rheumatoid arthritis, diabetes, or positive urine glucose slide test results excluded from study. 12 (48%) of those with CTS had bilateral diagnosis. The authors stated that the left hand is the dominant working hand in sawing, the right hand acting more to direct the saw during the operation.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	Referent group	RR, OR, or PRR	95% CI	Comments
Liss et al. 1995	Cross-sectional	1,066 of 2,142 dental hygienists from Ontario Canada Dental Hygienists Association compared to referent group, 154 of 305 dental assistants.	Outcome: Mailed survey, 2 CTS case definitions: (1) based on positive response to "told by a physician that you had CTS", (2) if during last 12 months, for >7 days experienced numbness and tingling, pain, or burning in distribution of median nerve, night pain or numbness in hands, and no previous wrist/hand injury. Exposure: Based on mailed survey: Length of practice, days/wk worked, patients/day, patients with heavy calculus, percent of time trunk in rotated position relative to lower body, instruments used, hr of typing/wk, type of practice.	Responder told that they had CTS: 7% Question-naire based CTS: 11%	Responder told that they had CTS: 0.9% Question-naire based CTS: 3.0%	OR=5.2 OR=3.7	0.9-32 1.1-11.9	Participation rate: 50% response rate from both groups. Study population >99% female. OR were age adjusted. Confounders considered included typing, hobbies, and taking estrogens.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Loslever and Ranaivosoa 1993	Cross-sectional	17 selected jobs with frequent and repeated absences of workers due to CTS investigated at the request of occupational doctors and managers. Biomechanical data recorded on a number of workers from each job, ranging from 1 to 4 workers. Involving 961 workers.	Outcome: Occupational physician from each factory involved in the study completed questionnaire concerning each job and the number of CTS cases. The prevalence of CTS was then calculated from ratio of CTS cases and total number of employees that worked at that place. Exposure: Videotaping of movements, use of vibrating tools, and two measurement techniques used: (1) Flexion-extension measurements: Subjects recorded at several points during the day for 15 min. An angle meter used to measure flexion-extension angles of the wrist: Rated high flexion, low flexion, low extension, and high extension using fuzzy cutting functions. Each modality characterized by its arithmetic mean and its relative duration. (2) Force: Electromyography used; values under 2 daN considered as low forces. Calculated time spent over 2 daN, maximal force, number of peak exertions, and the arithmetic mean of the n values during a period.	Mean prevalence rate among jobs (jobs chosen at workplaces where CTS had been reported): 35% (range 8 to 66%); prevalence of CTS in both hands: 20%		High force with high flexion and CTS: r=0.62 High force and high extension and CTS: r=0.29		Participation rate: Cases selected. Occupational doctor supplied information on gender, age, years on the job, hand orientation, has or has not contracted CTS. Subjects spent 60 to 80% of their time in extension ranging from 13 to 30E. Vibratory tools more often used in tasks with high prevalence of CTS (27%) than in ones with low prevalence of CTS (13%). 92% of population were female. Non-standard data analysis approaches, no statistical testing. Examiners not blinded. Authors believe higher rate of CTS in both hands (20%) vs. dominant hand (100%) argue for non-occupational factors being more important.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	Referent group	RR, OR, or PRR	95% CI	Comments
Marras and Shoenmarklin 1993	Cross-sectional	40 volunteers at a highly repetitive, hand-intensive industrial jobs in 8 different plants. Half the workers were employed in jobs that had OSHA recordable repetitive trauma incidents, half the workers were in jobs with no history of recordable repetitive trauma incidents. Two subjects from 10 repetitive, hand-intensive jobs were randomly chosen to participate.	Outcome: CTS was determined from evaluation of OSHA illness and injury logs and medical records. The independent variable was exposure to jobs in which CTS had occurred previously. A low-risk job was defined as having a zero incidence rate; a high-risk job was defined as having an incidence rate of eight or more recordable repetitive trauma. Exposure: Included number of wrist motions/8-hr shift, weight of loads, handgrip types and forces, work heights, and motion descriptions. Wrist motion monitors measured in the radial/ulnar, flexion/extension, and pronation/supination planes: wrist angles, angular velocity, angular acceleration.	High-risk job: 8 incidents/ 200,000 hr exposure	Low-risk job: 0 incidents	Model for predicting high vs. low job risk based upon motion component: Position Radial/ulnar ROM: OR=1.52 Flexion/extension ROM: OR=1.3 Pronation/ supination ROM: OR=1.2 Velocity Radialulnar vel: OR= 2.4 Flexion/ extension vel: OR=3.8 Pronation/ supination vel: OR=1.9 Acceleration Radial/ulnar accel: OR=2.7 Flexion/ extension accel: OR=6.1 Pronation/ supination accel: OR=2.96	 1.1-2.1 1.0-1.7 0.9-1.6 1.3-4.3 1.5-9.6 1.2-3.2 1.5-4.9 1.7-22 1.4-6.4	Participation rate: Not reported. Examiners blinded: not stated. Confounders controlled for: Age, gender, handedness, job satisfaction. All the jobs required gloves except two-one "low-risk" and one "high-risk." Significant difference between groups with regards to age, years with the company, and trunk depth. No significant difference in job satisfaction, number of wrist movements, age, weight, stature, hand dimensions. Turnover rate: High-risk jobs: 33%; low-risk jobs: 0.5%. Grip forces were three times as great in the high-risk jobs than in the low-risk jobs. Variance between subjects within jobs accounted for a substantial percentage of total variance in wrist motion.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
McCormack et al. 1990	Cross-sectional	Textile workers: 4 broad job categories involving intensive upper extremity use. Workers randomly chosen: Sewing workers (n=562); boarding workers (n=296); packaging workers (n=369); and knitting workers (n=352) compared to other non-office workers (n=468).	Outcome: Assessed by questionnaire and screening physical examination initially by nurse. CTS diagnosed on clinical grounds of symptoms and positive Tinel's sign and Phalen's test. Physician reassessed physical findings by "standardized methods." Exposure: Assessment by observation of jobs. Exposure to repetitive finger, wrist and elbow motions assumed from job title; no objective measurements performed.	Prevalences of CTS Boarding: 0.7% Sewing: 1.2% Packaging: 0.5% Knitting: 0.9%	1.3% (non-office)	Boarding vs. non-office OR=0.5 Sewing vs. non-office OR=0.9 Packaging vs. non-office OR=0.4 Knitting vs. non-office OR=0.6	0.05-2.9 0.3-2.9 0.04-2.4 0.1-3.1	Participation rate: 91%. Physician or nurse examiners not blinded to case or exposure status (personal communication). Prevalence higher in workers with <3 years of employment. Race and age not related to outcome. Females found to have significantly more CTS than males. Job category not found to be significant, however no measurement of force, repetition, posture analysis, etc. Questionnaire asked types of jobs, length of time on job, production rate, nature and type of upper extremity complaint, and general health history. 11 physician examiners; interexaminer reliability potential problem acknowledged.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Moore and Garg 1994	Cross-sectional	32 jobs in which 230 workers were employed. This study was more an evaluation of jobs than of individuals.	Outcome: CTS identified from OSHA logs and medical records. A case required electrophysiologic testing, confirmed as abnormal by electromyographer and presence of suggestive symptoms. Exposure: Observation and videotape analysis of jobs. Force, wrist posture, grasp type, high-speed work, localized mechanical stress, vibration, cold, and work time assessed via observation of videotape. Jobs classified as hazardous or safe based on data and judgement.	13.7%	4.9%	2.8	0.2-36.7	Participation rate: Study based on records. Investigators blinded to exposure, case outcome status, and personal identifiers on medical records. Repetitiveness, "type of grasp" were not significant factors between hazardous and safe job categories. No pattern of morbidity according to date of clinic visits. Strength demands significantly increased for hazardous job categories compared to safe job categories. IR based on full-time equivalents and not individual workers, may have influenced overall results. Workers had a maximum of 32-months of exposure at plant–so duration of employment analysis limited. Average maximal strength derived from population-based data stratified for age, gender, and hand dominance. Using estimates of Silverstein's classification, association between forcefulness and overall observed morbidity was statistically significant; repetition was not. No control for confounders. No information on work history, number of unaffected workers, or exposure duration.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Morgenstern et al. 1991	Cross-sectional	1,058 female grocery cashiers from a single union. Comparison group was those who reported no symptoms. Cashiers were also compared to results from a general population study from Rochester, Minnesota (Stevens et al. 1988).	Outcome: Defined CTS as self-reported hand/wrist pain, nocturnal pain, tingling in the hands or fingers, and numbness. Exposure: Duration, use of laser scanner determined from survey (no measurements).	12%	5.4%	For a difference of 25 hr/wk: 1.88	0.9-3.8	Participation rate: 82%. Controlled for age. Information collected on age, sex, pregnancy status, work history as a checker, specific job-related tasks, use of selected drugs, history of wrist injury. In logistic regression, “Use of diuretics” significantly associated with CTS, OR=2.66 (1.00-7.04); thought to be related to fluid retention by authors. Laser scanning found not to be significant factor.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Nathan et al. 1988	Cross-sectional	471 industrial workers from 27 occupations in 4 industries. Jobs grouped into 5 classes based on resistance and repetition rate.	Outcome: Case defined as NCS-determined impaired sensory conduction (sensory latency). Sensory latencies assessed antidromically for eight consecutive 1-cm segments of the nerve. A maximum latency difference of 0.4 ms or greater used to define impaired sensory conduction. Case definition did not deal with symptoms. Exposure: Jobs grouped into 27 occupations with similarities of characteristics as to type of grip, wrist position, handedness pattern, resistance, frequency, and duration of grasp and presence of vibratory and ballistic components. The 27 occupations then grouped into 5 classes. Resistance (Res.) rated from very light to very heavy; repetition rate rated from low to high. Group I: very light resistance and low repetition Group II: light resistance and very high repetition Group III: moderate resistance and moderately high repetition Group IV: heavy resistance and moderate repetition Group V: very heavy resistance and high repetition.	Prevalence of abnormal nerve conduction sensory latency: Group II: 27% Group III: 47% Group IV: 38% Group V: 61%	Prevalence of abnormal nerve conduction sensory latency: Group I: 28%	Group II vs. I: PR=1.0 Group I vs. III: PR=1.9 Group I vs. IV: PR=1.7 Group I vs. V: PR=2.0	0.5-2.0 1.3-2.7 1.3-2.7 1.1-3.4	Participation rate: Not reported. Analysis controlled for age and gender. No description of symptom status for defining CTS. Method of categorization of jobs and occupations not described. Classification system is based on only repetition and not resistance as listed. Initially excluded cases of CTS in study population, yet was supposedly identifying prevalences of CTS in exposure groups. For nerve conduction analysis, wrongly assumed that each hand's nerve conduction study results in an individual were independent. The 2 hands in a single individual are not independent of each other.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Nathan 1992a	Long-itudinal	315 workers using both hands (each hand analyzed separately) from four industries. These represented 67% of original group of workers from 1988 published study randomly selected from four industries (67% of original subjects) Group I: Very light resistance and low repetition Group II: Light resistance and very high repetition Group III: Moderate resistance and moderately high repetition Group IV: Heavy resistance and moderate repetition Group V: Very heavy resistance.	Outcome: Case defined as NCS-determined impaired sensory conduction (sensory latency). Sensory latencies assessed antidromically for eight consecutive 1-cm segments of the nerve. A maximum latency difference of 0.4 ms or greater used to define impaired sensory conduction. Probable CTS: Presence of any two primary symptoms (numbness, tingling, nocturnal awakening) or one primary symptom and 2 secondary symptoms (pain, tightness, clumsiness). Exposure: For this article, previous exposure classification was used from 1988 Nathan article. Jobs had been grouped into 27 occupations with similarities of characteristics as to type of grip, wrist position, handedness pattern, resistance, frequency, and duration of grasp and presence of vibratory and ballistic components. The 27 occupations then grouped into 5 classes. Resistance rated from very light to very heavy; repetition rate rated from low to high.	Group II: 19% Group III: 26% Group IV: 24% Group V: 18%	Group 1: 18%	Groups II vs. Group I: PR=1.1 Group III vs. Group I: PR=1.5 Group IV vs. Group I: PR=1.4 Group V vs Group I: PR=1.0	0.6-1.9 1.0-2.2 0.9-2.1 0.5-2.2	Participation rate: Overall: 67%; Group 3 participation rate was 59%. Examiners blinded: Not reported. Analyzed using gender, hand dominance, occupational hand use, duration of employment, and industry. 76% of participants employed in same occupational hand-use class as in 1988. A lower percentage of novice workers returned (56%) than non-novice workers (69%) for follow-up study. Analysis of "hands" instead of individual would cancel contribution of exposure effect if there was unilateral slowing. Data in table two for 1984 subjects is not the same data as presented in previous article; numbers have shifted to other groups. The significant difference seen between nerve slowing between Class 1 and Class 5 in 1988 paper is no longer significantly different. Authors note that "130 hands experienced a decrease in occupational use." No parameters given for decrease and assumption is made that both hands in an individual had similar decrease in use. With one-third of cohort missing from 1984 study, there is no way to determine if homogeneity in symptoms prevalence in 1984 and 1989 reflects absence of progression or drop-out.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Nathan 1994b	Long-itudinal	101 Japanese furniture factory workers. There were 27 managers, 35 clerical workers, 21 assembly-line or food service workers and 18 machine operators. Their NCS results were compared to 315 workers using both hands (each hand analyzed separately) from four industries. (These represented 67% of original group of workers from 1988 published study randomly selected from four industries (67% of original subjects) and are the subject of a separate table entry in this document. Group I: Very light resistance and low repetition. Group II: Light resistance and very high repetition. Group III: Moderate resistance and moderately high repetition. Group IV: Heavy resistance and moderate repetition. Group V: Very heavy resistance.	Outcome: Case defined as NCS-determined impaired sensory conduction (sensory latency). Sensory latencies assessed antidromically for eight consecutive 1 cm. segments of the nerve. A maximum latency difference of 0.4 ms or greater used to define impaired sensory conduction. Probable CTS: Presence of any two primary symptoms (numbness, tingling, nocturnal awakening or one primary symptom and 2 secondary symptoms (pain, tightness, clumsiness). Exposure: Exposure was not addressed except is assumed to be self-reported by questionnaire for the Japanese workers. The jobs were grouped into 5 classes. Resistance rated from very light to very heavy; repetition rate rated from low to high repetition.	8 cm. Sensory latency: 0.30 14 cm. Sensory latency: 0.36 Probable CTS: 2.5% Definite CTS: 2.0	8 cm. Sensory latency: 0.31 14 cm. Sensory latency: 0.45 Probable CTS: 2.0% Definite CTS: 8.3			Participation rate: For Japanese Workers: 100% Americans: Overall: 67%; Group 3 participation rate was 59%. Examiners blinded: Not reported. Analyzed using gender, hand dominance, occupational hand use, duration of employment, and industry. Analysis of “hands” instead of individual would cancel contribution of exposure effect if there was unilateral slowing. Conducted step-wise regression analysis for Probable CTS and reported that repetitions and duration of employment were protective. Cigarettes and Age were also retained in the model.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Osorio et al. 1994	Cross-sectional	56 supermarket workers. Comparison was between high and low exposure groups.	Outcome: CTS assessed via medical history, physical exam, median nerve conduction studies, and vibratory thresholds. A. CTS-like syndrome: Probable diagnosis: (1) Pain tingling numbness in median nerve distribution and (2) symptoms last >1 wk or $ 12 times in last year, no acute trauma or systemic disease, onset or exacerbation since working on current job. B. Median neuropathy: Sensory median nerve conduction velocity 44 m/sec or less. Exposure: Observation of jobs by ergonomist and industrial hygienist. Analysis based on categorization by job title after observation. Jobs divided into 3 categories based on the likelihood of exposure to forceful and repetitive wrist motions (low, moderate, high), years worked at this store, total years worked as checker, total years using laser scanners.	Symptoms: 63% in high-exposure; 10% in moderate-exposure group Positive NCS: 33% in high-exposure; 7% in moderate-exposure group	0% for low-exposure group 0% for low-exposure group	8.3 (for CTS-symptoms high vs. low exposure groups) 6.7 (for abnormal NCS, high vs. low exposure groups)	2.6-26.4 0.8-52.9	Participation rate: 81%. Adjusted for age, gender, alcohol consumption, and high-risk medical history. Interview and testing procedures performed by personnel blinded to case status. Skin surface temperature not controlled. Dose response for presumptive (symptoms of) exposure to forceful, repetitive wrist motion: CTS-prevalence 63% high exposure; 10% medium exposure; 0% low exposure. Dose response for prevalence of abnormal median nerve velocity: 33% high; 7% medium; 0% low. Linear regression showed significant relationship between years worked and worsening of nerve conduction (decreased nerve conduction velocity and decreased nerve conduction amplitude) adjusted for confounders (above), however small sample size.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	Referent group	RR, OR, or PRR	95% CI	Comments
Punnett et al. 1985	Cross-sectional	162 female garment workers; 85% were employed as sewing machine operators who sewed and trimmed by hand. Comparison: 76 of 190 full- or part-time workers on day shift in a hospital who worked as nurses or aids; lab technicians or therapists, or food service workers. Employees typing >4 hr/day excluded from comparison group. 162 female garment workers compared to 73 female hospital workers.	Outcome: CTS assessed by symptom questionnaire and physical exam. Cases defined as the presence of persistent pain (lasted for most days for one month or more within the past year); were not associated with previous injury; and, began after first employment in garment manufacturing or hospital employment. Key questions based on the arthritis supplement questionnaire of the National Health and Nutrition Examination Survey (NHANES). Median nerve symptoms (pain, numbness, or tingling) if present at night or early in the morning or met 2 of 3 criteria: (1) accompanied by weakness in pinching or gripping; (2) alleviated by absence from work for >1 wk; (3) aggravated by housework or other non-occupational tasks. Exposure: Observation of job tasks. Information on work history obtained by questionnaire. Job title used as a proxy for exposure in analyses.	18%	6%	2.7	1.2-7.6	Participation rate: 97% (garment workers), 40% (hospital workers). Controlled for age, hormonal status, and native language. Pain in the wrist and hand significantly correlated (*p*<0.01; r=0.41). Age distribution not significantly different metabolic disease. Symptoms of CTS showed trend by age (*p*<0.01). Prevalence of pain not associated with years of employment in garment workers. Length of employment not predictor of risk. Change in hormonal status significantly associated with CTS symptoms but negatively associated with employment in garment shop. Logistic model found garment work and age significant for symptoms of CTS. Neither metabolic disease nor change in hormonal status statistically significant risk.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	RR, OR, or PRR	95% CI	Comments
Schottland et al. 1991	Cross-sectional	Poultry workers (27 males, 66 females) compared to job applicants (44 males, 41 females).	Outcome: Defined as prolonged motor or sensory median latencies. No symptoms or physical exam included in case definition. Exposure: Based on current employment status at plant. No measurements made. Repetitive tasks (15 to 50 complex operations/min not rare), requiring firm grip, with wrists in flexion or extension, with internal deviations.	41% exceeding 2.2 ms for sensory latency value of median nerve on NCS (right-hand, females, corrected for age)	20% exceeding 2.2 ms for median sensory latency value (right-hand, females, corrected for age)	2.86	1.1-7.9	Participation rate: Not reported. Not mentioned whether examiners blinded to case status or exposure. Controlled for age and gender. Referents not excluded if prior employment at poultry plant; 15 referents had previous employment in poultry plant; this would result in poor selection of controls, would tend to bias results towards the null.
				24% exceeding 2.2 ms for median nerve sensory latency value on NCS (left-hand, females, corrected for age)	15% exceeding 2.2 ms for median nerve sensory latency value on NCS (left-hand, females, corrected for age)	1.87	0.6-9.8	Right-hand of female applicants who never worked in a poultry plant had significantly longer median palmar latency (MPS) on nerve conduction than referents (*p*<0.04). Symptoms of CTS not inquired. Right hand of male workers had longer MPS on nerve conduction but not significant (*p*<0.07). From Table 5-2 in paper it shows there is inadequate sample size for detecting differences in female's left-hand and male's left- and right-hand MPS. Concluded there is an elevated risk of CTS, roughly equal to risk from aging for the right hands of female workers, less risk for male both hands and female left hands.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	Referent group	RR, OR, or PRR	95% CI	Comments
Silverstein et al. 1987	Cross-sectional	652 industrial workers in 4 groups: (1) low-force, low-repetition (comparison group, n=93 males, 64 females); (2) high-force, low-repetition (n=139 males, 56 females); (3) low-force, high-repetition (n=43 males, 100 females); (4) high-force, high-repetition (n=83 males, 74 females).	Outcome: CTS determined by medical examination and interviews. Symptoms of pain, numbness or tingling in median nerve distribution. Nocturnal exacerbation; symptoms >20 times or >1 wk in previous year; no history of acute trauma; no history of rheumatoid arthritis; onset of symptoms since current job; positive modified Phalen's test (45 to 60 sec) or Tinel's sign; rule out cervical root thoracic outlet, pronator teres syndrome. Exposure: To (1) forceful, (2) repetitive, and (3) awkward hand movements assessed by EMG and video analysis of jobs. Three workers in each selected job videotaped for (at least) 3 cycles. High-force job: A mean adjusted force >6 kg (mean adjusted force = [(variance/mean force)+ mean force]); low-force job: A mean adjusted force <6 kg. High repetition = work cycles <30 sec or work cycles constituting >50% of the work cycle.	1.0 (Group 2) 2.1 (Group 3) 5.6 (Group 4)	0.6	Group 2 vs. Group 1: OR=1.8 Group 3 vs. Group 1: OR=2.7 Group 4 vs. Group 1: OR=15.5 In separate logistic models: (1) Repetitiveness: OR=5.5 ($p<0.05$) (2) Force: OR=2.9 (non-significant)	0.2-21 0.3-28 1.7-142	Participation rate: 90% response rate obtained. Controlled for age, gender, plant, years on the job. No interactions found. Jobs evaluated by investigators blinded to worker health status. Examiner blinded to medical history and exposure. Random sample of 12 to 20 active workers/job with 1 year's seniority, stratified by age and gender. Interview data included prior health and injuries, chronic diseases, reproductive status of females, recreational activities, prior job activities. No association found with wrist posture, type of grasp, or use of vibrating tool. Positive associated with age but not statistically significance. No differences in health history or recreational activities. No association with gender, or industrial plant. Negatively associated with years on the job but not statistically associated. Repetitiveness found to be stronger risk factor than force. No association with hormonal status.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Stetson et al. 1993	Cross-sectional	Comparison of 137 asymptomatic industrial workers, 103 industrial workers with hand/wrist symptoms, and 105 control subjects randomly selected not exposed to highly forceful or repetitive hand exertions.	Outcome: Symptoms consistent with CTS defined as numbness, tingling, or burning localized to median nerve anatomic area, not caused by acute injury, and occurred >20 times in previous year. Nerve conduction studies conducted on the dominant hand; median sensory and motor, ulnar sensory, distal amplitudes and latencies were measured. Temperature monitored. Exposure: Observation and worker interviews using ergonomic checklist. One or more workers on each job were evaluated based on repetitiveness, forcefulness, mechanical stress, pinch grip, and wrist deviation, then data extrapolated to other workers performing jobs. A 3-point ordinal scale used to estimate exposure (none, some, frequent or persistent).			Õ	Õ	Participation rate: 71% seen, 16% refused, others unavailable because of layoffs, transfers, or sick leave. Industrial population randomly selected. Controlled for age, height, skin temperature, and dominant index finger circumference. Comparing the means of the nerve conduction measures, the following were statistically significantly different between: (1) the asymptomatic hand group and the controls: median sensory amplitude and distal latency, and median to ulnar comparison measures; (2) the symptomatic hand group and controls: median sensory distal latency, and median to ulnar comparison measures. Median sensory amplitudes were smaller and distal latencies longer in symptomatic compared to asymptomatic hand group. Forceful hand and upper extremity exertions were significantly different between exposed and non-exposed groups. Repetition not significantly different, but little statistical power to detect difference.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Tanaka et al. *In Press*	Cross-sectional interview survey	Data from the Occupational Health Supplement of 1988 National Health Interview Survey conducted by the National Center for Health Statistics. Households are selected by multistage probability sampling strategy. One adult, 18 years or older, was randomly selected for interview. 44,233 interviews completed.	Outcome: Outcomes included those "Recent Workers" who worked anytime during the past 12 months (excluding armed forces). Self-reported carpal tunnel syndrome= "yes" to question: During the past 12 months, have you had a condition affecting the wrist and hand called carpal tunnel syndrome? Medically called CTS = a response of "carpal tunnel syndrome" to the question: "What did the medical person call your hand discomfort?" Exposure: By questionnaire: Did the most recent job require you to bend or twist your hands or wrists many times an hr? Did you work with hand-held or hand-operated tools or machinery.	Prevalence of self-reported CTS among recent workers: 1.47% Prevalence of medically called CTS among recent workers: 0.53%		Logistic model for medically called CTS among recent workers Bend/twist: OR=5.9 White race: OR=4.2 Female gender: OR=2.4 Vibration: OR=1.85 BMI $25: OR=2.1 Cigarette use: OR=1.6 Age $40: OR=1.3 Annual income $$20,000: OR=1.5 Education >12: OR=1.2	3.4-10.2 1.9-15.6 1.6-3.8 1.2-2.8 1.4-3.1 1-2.5 0.2-1.9 1-2.4 0.8-1.8	Participation rate: 91.5%. Multiple logistic regression used to examine age, gender, race, exposure to vibration, and bending/twisting of the hand/wrists to odds of reporting CTS. Interactions were checked for. Self-reported CTS prevalence among recent workers higher in whites compared to non-whites, highest in white females. When vibration was not in the model the bend/twist OR=5.99. When bend/twist is not in the model, vibration OR=3.00. Major limitation is CTS is based on self-reports without medical validation. No temporal relationship could be found between reported CTS and the reported occupation/industry or exposure to bending/twisting of the hand/wrist.

(Continued)

Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

				MSD prevalence				
Study	**Study design**	**Study population**	**Outcome and exposure**	**Exposed workers**	**Referent group**	**RR, OR, or PRR**	**95% CI**	**Comments**
Weislander et al. 1989	Case-control	34 male CTS patients, each matched to 2 other hospital referents (drawn from among other surgical cases, one referent had been operated on for gall bladder surgery and the other for varicose veins) and 2 population referents (from a general population register and telephone directory) (total comparison group=143 males).	Outcome: CTS diagnosed clinically by a hand surgeon, confirmed by electro-diagnostic studies. Exposure: To vibrating tools, repetitive wrist movements, and loads on the wrist assessed via telephone interview using a standardized questionnaire. The degree of exposure was evaluated both with regard to the total number of work years and the average number of exposed hr a wk. Repetitive movements classified independently by physician interviewer and occupational hygienist. Exposure to repetitive wrist movements was considered to exist if they agreed.	õ	õ	Cases compared to all referents (hospital- and population-based): Vibrating tool use: OR=3.3 Use of hand-held vibrating tools 1-20 years: OR=2.7 Loads on the wrist: OR=1.8 Cases compared to population referents alone: Vibrating tool use: OR=6.1 Repetitive wrist movement for >20 years: OR=4.6 Repetitive wrist movement: OR=2.7 Obesity: OR=3.4	1.6-6.8 1.1-6.7 1.0-3.5 2.4-15 1.8-11.9 1.3-5.4 1.2-9.8	Participation rate: 93%. Referents matched for gender and age (±3 years.), hospital referents for year of operation. Hospital referents and population referents statistically different comparing: use of vibrating tool, repetitive movements of wrist, workload on wrist, obesity. Hospital-based population may not reflect industrial workplace. Interviewers not blinded to case status. Elevated OR for repetitive movements of the wrist only statistically significant for the category '>20 years.' Odds ratios (OR) for any of the three diseases (thyroid disease, diabetes, rheumatoid arthritis) found to be statistically significant among cases with CTS compared to 143 referents; OR=2.8 (1.0-7.6). ORs tended to increase with increasing number of risk factors present. One factor, OR=1.7 (0.6-4.4); two factors, OR=3.3 (1.2-9.1); >two factors, OR=7.1 (2.2-22.7). Obesity is >10% above reference weight.

CHAPTER 5b
Hand/Wrist Tendinitis

SUMMARY

Eight epidemiologic studies have examined physical workplace factors and their relationship to hand/wrist tendinitis. Several studies fulfill the four epidemiologic criteria that were used in this review, and appropriately address important methodologic issues. The studies generally involved populations exposed to a combination of work factors; one study assessed single work factors such as repetitive motions of the hand. We examined each of these studies, whether the findings were positive, negative, or equivocal, to evaluate the strength of work-relatedness, using causal inference.

There is **evidence** of an association between any single factor (repetition, force, and posture) and hand/wrist tendinitis, based on currently available epidemiologic data. There is **strong evidence** that job tasks that require a combination of risk factors (e.g., highly repetitious, forceful hand/wrist exertions) increase risk for hand/wrist tendinitis.

INTRODUCTION

Since the hand/wrist area may be affected by more than one musculoskeletal disorder, only those studies that specifically address hand/wrist tendinitis are considered here. Studies with outcomes described as hand/wrist disorders or symptoms in general, or those in which hand/wrist tendinitis was combined with epicondylitis, e.g., were excluded from this section because it was not possible to evaluate evidence for work-related hand/wrist tendinitis from the data. The seven studies referenced in Table 5b-1 provided data specifically addressing hand/wrist tendinitis. In each of these studies the outcome was determined using physical examination criteria, although the case definitions varied among studies. Prevalence or incidence rates of hand/wrist tendinitis reported in these exposed groups ranged from 4% to 56%, and in unexposed groups from 0% to 14%. Such wide ranges of prevalence rates probably reflect the variability in diagnostic criteria as much as they do the range of workplace exposures in these studies. For example, one study used very strict criteria [Byström et al. 1995]. The case definition required observation of swelling along the tendon at the time of the physical examination. The only cases of tendinitis diagnosed were deQuervain's disease; no other cases of tenosynovitis or peritendinitis were diagnosed among 199 automobile assembly line workers. In contrast, the studies with the highest prevalence rates either did not clearly state what diagnostic criteria were used to determine the case definition, or the case definition considered recurrences of tendinitis new cases. Whether case definitions were inclusive or exclusive would not affect the relative risk (RR) as long as they were applied non-differentially between groups designated as exposed or unexposed.

Although several studies reported odds ratios, published data were reanalyzed and the results presented here and in Tables 5b1-3 as prevalence ratios (PRs). This was done because odds ratios may overestimate RR when prevalence rates are high, and to make estimates of RR comparable across studies. In studies that presented odds ratios in the original articles, the recalculation of data as PRs resulted in lower estimates of the RR. In the one prospective cohort study [Kurppa et al. 1991] incidence rates and risk ratios are presented.

Except for a study reported by Armstrong et al. [1987a], risk estimates were not reported separately for single risk factors. Only the Armstrong et al. study used a formal quantitative exposure assessment as the basis for determining exposure groups. Other studies grouped jobs with similar risk factors together and compared them to jobs without those risk factors. Typically, the selection of jobs for the exposed and unexposed groups was based on general knowledge of the jobs, previously published literature, or questionnaire data. Repetition, force, and extreme postures were considered in combination to determine which workers were exposed or unexposed. Formal exposure assessment (such as videotape analysis for cycle time, repetition, extreme postures, and estimates of force), was usually conducted on a sample of jobs and used as rationale in the grouping of jobs into exposed and unexposed categories, rather than to create quantitative measures of risk factors. In some cases (e.g., Luopajärvi et al. [1979]), investigators noted the difficulty in examining risk factors separately because of job rotation. For the purpose of this review, we have grouped study findings according to the risk factors present in the exposed job categories, based on the information in published articles. In Tables 5b1–3, studies are listed under single risk factors if there was evidence that the exposed and unexposed groups differed in that risk factor, though the risk estimates mostly refer to combined exposures.

REPETITION

Definition of Repetition for Hand/Wrist Tendinitis

Armstrong et al. [1987a] analyzed videotaped job tasks of a sample of workers, then divided job tasks according to level of repetitiveness: high repetition (cycle time <30 sec, or $50% of the cycle spent performing the same fundamental motions) or low repetition. Kuorinka and Koskinen [1979] created a "workload index" based on the number of pieces handled per hour multiplied by the number of hours worked, for a dose-response analysis within the exposed group. Comparison groups in the other studies were job categories; selection of the groups to be compared was based on observations, questionnaire data, or surveillance data.

Studies Reporting on the Association of Repetition and Hand/Wrist Tendinitis

Seven studies addressed repetition: Amano et al. [1988]; Armstrong et al. [1987a]; Byström et al. [1995]; Luopajärvi et al. [1979]; Roto and Kivi [1984]; Kuorinka and Koskinen [1979]; and McCormack et al. [1990].

Studies Meeting the Four Evaluation Criteria

Two of the seven studies that addressed repetition met all four of the evaluation criteria: Armstrong et al. [1987a], and Luopajärvi et al. [1979]. Armstrong et al. studied 652 industrial workers at seven manufacturing plants (electronics, sewing, appliance, bearing fabrication, bearing assembly, and investment casting). Exposure assessment of jobs included videotape analysis and electromyography (EMG) of a sample of workers. Data from this assessment were then used to categorize jobs according to level of repetitiveness and force. Health assessment of workers focused on deQuervain's disease, trigger finger, tendinitis, and tenosynovitis. The hand/wrist tendinitis case definition required abnormal physical examination findings (increased pain with resisted but not passive motion or tendon locking with a palpable nodule, or a positive Finkelstein's test) in addition to meeting symptom criteria on standardized interviews. The PR for the high repetition/low force group (n=143) compared to the low repetition/low force group (n=157) was 5.5 (95% confidence interval [CI] 0.7–46.3). The PR for the high repetition/high force group (n=157) compared to the low repetition/low force group (n=157) was 17.0 (95% CI 2.3–126.2). The effect of age, gender, years on the job, and plant were analyzed. A higher prevalence of tendinitis was noted among women but was not significantly associated with personal factors, whereas significant differences in posture were observed between males and females.

Luopajärvi et al. [1979] compared the prevalence of hand/wrist tendinitis among 152 female assembly line packers in a food production factory to 133 female shop assistants in a department store. Exposure to repetitive work, awkward hand/arm postures, and static work was assessed by observation and videotape analysis of factory workers. No formal exposure assessment was conducted on the department store workers; their job tasks were described as variable. Cashiers were excluded, presumably because their work was repetitive. The health assessment consisted of interviews and physical examinations conducted by a physiotherapist (active and passive motions, grip-strength testing, observation, and palpation). Diagnoses of tenosynovitis and peritendinitis were later determined by medical specialists using these findings and predetermined criteria. The PR for tendinitis among the assembly line packers compared to the shop assistants was 4.13 (95% CI 2.63–6.49). Age, hobbies and housework were addressed and no associations with musculoskeletal disorders were identified.

Studies Meeting at Least One Criteria

Amano et al. [1988] reported the prevalence of cervicobrachial disorders, including tenosynovitis, among 102 assembly line workers in an athletic shoe factory and 102 age- and gender-matched non-assembly line workers (clerks, nurses, telephone operators, cooks, and key punchers). Exposure assessment was based on videotape analysis of the tasks of 29 workers on one assembly line. Assembly line workers produced about 3,400 shoes a day. All but one task had cycle times less than 30 seconds. No formal exposure assessment of the comparison group was reported. Diagnoses were determined by physical examination, including palpation for tenderness. The PRs for tenosynovitis of the right and left index finger flexors among the shoe factory workers were 3.67 (95% CI 1.85–7.27) and 6.17 (95% CI 2.72–13.97) respectively, compared to the non-factory workers. Tenosynovitis of the other digits was not diagnosed in the comparison group. Shoe assembly workers held shoe lasts longer in the left hand and had greater frequency of symptoms in the left hand. Comparison subjects were matched to shoe factory workers on gender and age (within five years).

Byström et al. [1995] studied forearm and hand disorders among 199 automobile assembly line workers and compared them to 186 randomly selected subjects from the general Swedish population. For both groups, exposure was assessed using rating scales on nurse-administered questionnaires that addressed daily duration of hand and finger movements, wrist position, grip, and hand tool use [Fransson-Hall et al. 1995]. Videotape analysis and electromyograms were conducted on a subgroup [Hägg et al. 1996]. A diagnosis of tenosynovitis or peritendinitis required the observation of swelling and pain during active movement on physical examination. A diagnosis of deQuervain's disease required a positive Finkelstein's test. No cases of tenosynovitis or peritendinitis, other than deQuervain's disease, were found in this study, probably because of strict clinical criteria used for the case definition. The PR for deQuervain's disease among the automobile assembly line workers was 2.49 (95% CI 1.00–6.23) compared to the general population group. Psychosocial variables and other potential confounders or effect modifiers were addressed by Fransson-Hall et al. [1995]. A higher prevalence of deQuervain's disease was noted among men than women.

Kuorinka and Koskinen [1979] studied occupational rheumatic diseases and upper limb strain among 93 scissor makers and compared them to the same group of department store assistants (n=143) that Luopajärvi used as a comparison group. Temporary workers and those with recent trauma were excluded from the scissor makers group. Exposure assessment included videotape analysis of scissor maker tasks. The time spent in deviated wrist postures per work cycle was multiplied by the number of pieces handled per hour and the number of hours worked to create a workload index. Cycle times ranged from 2 to 26 seconds; the number of pieces handled per hour ranged from 150 to 605. No formal exposure assessment was conducted on the shop assistants. Health assessment involved interview and physical examination by a physiotherapist following a standard protocol. Diagnoses of tenosynovitis and peritendinitis were later determined from these findings using predetermined criteria (localized tenderness and pain during movement, low-grip force, swelling of wrist tendons [Waris et al. 1979]). In equivocal cases, orthopedic and physiatric teams determined case status. The PR for muscle-tendon syndrome among the scissor makers was 1.38 (95% CI 0.76–2.51) compared to the department store assistants. Whether or not cashiers were excluded from the comparison group in this study, as they were in the Luopajärvi et al. [1979] study is unclear. The study group was 99% female. No relationship was found between age- or body-mass index and muscle-tendon syndrome. The number of symptoms increased with the number of parts handled per year. Analyses of subgroups of scissor makers showed non-significant increased prevalence of muscle-tendon syndrome in short versus long cycle tasks and in manipulation versus inspection tasks. The authors noted a lack of contrast in exposures between the subgroups. A non-significant trend of increasing prevalence of diagnosed muscle-tendon syndrome with increasing number of pieces handled per year was noted in a nested case-control analysis (n=36).

McCormack et al. [1990] studied tendinitis and related disorders of the upper extremity among

1,579 textile production workers compared to 468 non-production textile workers, a reference group that included machine maintenance workers, transportation workers, cleaners, and sweepers. The textile production workers were reported as being exposed to repetitive finger, wrist and elbow motions based on knowledge of jobs; no formal exposure assessment was conducted. Health assessment included a questionnaire and screening physical examination followed by a diagnostic physical examination. The diagnosis of tendinitis required positive physical findings suggestive of inflammation. The textile production workers were divided into four broad job categories: boarding (n=296), which was noted to require forceful work as well as the repetitive hand-intensive work of the other categories; sewing (n=562); packaging (n=369); and knitting (n=352). The PR for tendinitis among all textile production workers was 1.75 (95% CI 0.9–3.39), compared to the reference group non-production textile workers. The PRs and 95% CIs comparing tendinitis among each broad category of textile production workers to the reference group are as follows: boarding—3.0 (1.4, 6.4); sewing—2.1 (1.0, 4.3); packaging—1.5 (0.7, 3.5); and knitting—0.4 (0.1, 1.4). The authors noted that the knitting work was more automated than the other textile production job categories. Race and age were not related to outcome, but the prevalence of tendinitis was higher in workers with less than three years of employment. Female gender was a significant predictor of tendinitis (p=0.01), but job category was a stronger predictor (p=0.001).

Roto and Kivi [1984] studied the prevalence of tenosynovitis among 92 male meatcutters compared to 72 male construction foremen. No formal exposure assessment was conducted. Meatcutters' work entailed repetitive physical exertion of upper extremities and shoulders. Construction foremen's work did not involve repetitive movements of the upper extremities. Health assessment was by questionnaire and physical examination. Tenosynovitis was defined as swelling, local pain, and finger weakness during movement. The prevalence of tenosynovitis among the meatcutters was 4.5%. The PR for tenosynovitis as defined by physical examination could not be calculated because there were no cases among the comparison group. The PR of tendinitis-like symptoms reported on the questionnaire among the meatcutters was 3.09 (1.43, 6.67) compared to the construction foremen. Serologic testing for rheumatoid arthritis was done to control for potential confounding, none was detected. Authors noted that tenosynovitis occurred in younger age groups.

Strength of Association—Repetition and Hand/Wrist Tendinitis

The PRs for repetitive work and hand/wrist tendinitis in the studies reviewed above ranged from 1.4 to 6.2:

Repetition and Hand/Wrist Tendinitis

PR and 95% CI	Authors	Exposed/Unexposed Groups
5.5 (0.7–46.3) 17.0 (2.3–126.2)	Armstrong et al. [1987a]*	HI REP & LO FORCE/LO REP & LO FORCE HI REP & HI FORCE/LO REP & LO FORCE
3.7 (1.9–7.3) to 6.2 (2.7–14.0)	Amano et al. [1988]	Shoe assemblers/clerks, nurses, operators, cooks, keypunchers
2.5 (1.0–6.23)	Byström et al. [1995]	Auto assemblers/general population
1.4 (0.8–2.5)	Kuorinka and Koskinen [1979]	Scissor makers/department store assistants
1.8 (0.9–3.4)	McCormack et al. [1990]	Textile production/ maintenance workers, etc.
3.1 (1.4–6.7)	Roto and Kivi [1984]	Meatcutters/construction foremen
4.1 (2.6–6.5)	Luopajärvi et al. [1979]*	Food packers/department store assistants excluding cashiers

*Study met all four criteria.

In evaluating these RR estimates, study limitations should be considered in addition to statistical significance. Statistical significance addresses the likelihood that the results are not due to chance alone, whereas study limitations can bias the RR estimates in either direction. All of the PRs were greater than one, and four of the seven were statistically significant. The range (1.4–6.2) might reflect the level of contrast in repetitiveness between the exposed and comparison groups. For example, in McCormack et al. [1990], the comparison group consisted of machine maintenance workers, transportation workers, and cleaners and sweepers, whose exposure to repetition was not measured. If there were some exposure to repetitive work in the comparison group, then this would tend to decrease the RR for hand/wrist tendinitis among the textile workers. Another concern with this study is the possibility that the knitting workers may not have been exposed to very repetitive work due to greater automation in the knitting process. The effect of this potential misclassification of exposure would also be to decrease the RR.

Note that Kuorinka and Koskinen and Luopajärvi et al. both used the same comparison group, but the number of subjects in the department store assistant group was 143 for Kuorinka and Koskinen, and 133 for Luopajärvi (who excluded cashiers from the comparison group). If Kuorinka and Koskinen did not exclude cashiers, this might tend to decrease the RR.

The highest RR (6.2) reported for repetitive work was by Amano et al. [1988]. In this study it is unclear whether the examiner was blinded to whether the subjects were shoe assemblers or in the comparison group of non-assembly line workers that included clerks, nurses, telephone operators, cooks, and key punchers. Because the occupational groups were examined on separate dates blinding seems unlikely. The lack of a clear case definition leaves open the possibility of examiner bias, which might lead to an increased RR. Alternatively, if there were a significant number of key punchers in the comparison group, who may have been exposed to repetitive work, that would tend to decrease the contrast in exposure and might lead to a decrease in the RR.

In summary, the potential for underestimation of the RR has been noted in studies where the RR is at the low end of the range, and the potential for overestimation of the RR has been noted at the high end of the range. Considering these concerns and statistical significance, the RR for hand/wrist tendinitis attributable to repetitiveness is probably more likely to be in the middle range of the estimates, based on the studies reviewed. The statistically significant estimates of RR in this middle group range from 2.5 to 4.1.

Temporal Relationship—Repetition and Hand/Wrist Tendinitis

All of the studies reviewed for this section were cross-sectional, so proving that exposure to repetitive work occurred before hand/wrist tendinitis is not possible. However, information in several of the studies suggests the likelihood that exposure to repetitive work occurred before the diagnosis of tendinitis. For example, recently employed workers were excluded by Kuorinka and Koskinen [1979]. In Luopajärvi et al.'s [1979] study group, the minimum length of employment was 3 years. In the McCormack et al. [1990] study, the minimum average length of employment in the job categories was more than 7 years. Byström et al. [1995] noted that subjects were selected for clinical examination 5 months after completion of questionnaires on exposure. Roto and Kivi's [1984] subjects had all worked in the food industry for more than one year. Armstrong and Chaffin [1979] required a minimum length of employment of one year. Case definitions generally required that symptoms began after starting the current job or employment at the plant. This also suggests that exposure occurred before disease.

Consistency in Association for Repetition and Hand/Wrist Tendinitis

All of the studies reviewed showed positive RR estimates for hand/wrist tendinitis among occupational groups exposed to repetitive work, ranging from 1.4 to 6.2. Four of the seven studies resulted in statistically significant PRs. Considering only statistically significant estimates from studies not noted to have serious limitations (which might bias the RR), the range narrows to 2.5–4.1.

Coherence of Evidence for Repetition and Hand/Wrist Tendinitis

DeQuervain's disease and other tenosynovitis of the hand, wrist, and forearm have been associated for decades with repetitive and forceful hand activities as one of the possible causal factors [Amadio 1995]. DeQuervain's disease is the entrapment of the tendons of the extensor pollicis brevis and abductor pollicis longus. Other similar conditions are trigger thumb and triggering of the middle and ring fingers, characterized by pain with motion of the affected tendon. Despite the fact that the tendon and its sheath may be swollen and tender, the histopathology shows peritendinous fibrosis without inflammation, and fibrocartilaginous metaplasia of the tendon sheath tissue. The role of inflammation early in the process is not clear [Hart et al. 1995]. As in carpal tunnel syndrome or epicondylitis, acute classical inflammation does not seem a critical pathophysiological component of the clinical condition, at least once it becomes chronic. Despite the observations that too much forceful and repetitive activity contributes to carpal tunnel syndrome and epicondylitis, the response of the tendons and the muscles to repetitive activity is likely that of a U-shaped curve. Too little and too much activity may be harmful, but intermediate levels of activity are probably beneficial. The studies of tendon and muscle physiology suggest that a certain amount of activity maintains the normal state of these tissues and leads to adaptive changes. These tissues have the ability to repair significant amounts of damage from some overuse; the poorly understood issue is when overuse exceeds the ability of the tissue to repair the damage or triggers a more harmful type of damage [Hart et al. 1995]. Marras and Schoenmarklin [1991] reported that velocity and acceleration significantly predicted upper extremity musculoskeletal disorders (including tendinitis) among industrial workers performing hand-intensive job tasks.

Dose-Response Relationship For Repetition and Hand/Wrist Tendinitis

Kuorinka and Koskinen [1979] reported that within the group of scissor makers, increased prevalence of muscle-tendon syndrome occurred in short versus long cycle tasks and in manipulation versus inspection tasks. These increases were not statistically significant. The authors noted a lack of contrast in exposures between the subgroups. A non-significant trend of increasing prevalence of diagnosed muscle-tendon syndrome with increasing number of pieces handled per year was also noted in a nested case-control analysis (n=36) in the same study.

The Armstrong et al. [1987a] data resulted in a PR of 17.0 (2.3, 126.2) for jobs that were highly repetitious and required highly forceful exertions. This suggests a synergistic effect when both risk factors are present because the estimate is greater than the sum of the RR estimate for force or repetition alone.

Conclusions on Repetition and Hand/Wrist Tendinitis

There is strong evidence for a positive association between highly repetitive work, in combination with other job risk factors, and hand/wrist tendinitis based on currently available epidemiologic data. All seven of the studies reviewed reported positive RR estimates. Four of these estimates were statistically significant. Potential confounders (factors associated with both exposure and outcome that may distort interpretation of findings) considered in the studies of hand/wrist tendinitis included gender, age, other medical conditions, and outside activities. There is no evidence that the associations reported here between repetitive work and hand/wrist tendinitis are distorted by gender, age, or other factors.

FORCE

Definition of Force for Hand/Wrist Tendinitis

Armstrong et al. [1987a] based high and low force categories on electromyographs of forearm flexor muscles of representative workers. Comparison groups in the other studies were job categories; selection of the groups to be compared was based on observations, questionnaire data, or surveillance data.

Studies Reporting on the Association of Force and Hand/Wrist Tendinitis

Five studies addressed force: Armstrong et al. [1987a]; Byström et al. [1995]; Kurppa et al. [1991]; McCormack et al. [1990]; and Roto and Kivi [1984].

Studies Meeting the Four Criteria

One of the studies that addressed force met all four of the evaluation criteria: Armstrong et al. [1987a]. Armstrong et al. studied 652 industrial workers at seven manufacturing plants (electronics, sewing, appliance, bearing fabrication, bearing assembly, and investment molding). Exposure assessment of jobs included videotape analysis and EMG of a sample of workers. Data from this assessment were then used to categorize jobs according to level of repetitiveness and force. Health assessment of workers focused on deQuervain's disease, trigger finger, tendinitis, and tenosynovitis. The hand/wrist tendinitis case definition required abnormal physical examination findings (increased pain with resisted but not passive motion or tendon locking with a palpable nodule, or a positive Finkelstein's test) in addition to meeting symptom criteria on standardized interviews. The PR for the high force/low repetition group (n=195) compared to the low force/low repetition group (n=157) was 4.8 (95% CI 0.6–39.7). The PR for the high repetition/high force group (n=157) compared to the low repetition/low force group (n=157) was 17.0 (95% CI 2.3–126.2). The effect of age, gender, years on the job and plant were analyzed. A higher prevalence of tendinitis was noted among women, but was not significantly associated with personal factors, whereas significant differences in posture were observed between males and females.

Studies Meeting at Least One Criteria

Byström et al. [1995] studied forearm and hand disorders among 199 automobile assembly line workers and compared them to 186 randomly selected subjects from the general Swedish population. For both groups, exposure was assessed using rating scales on nurse-administered questionnaires that addressed daily duration of hand and finger movements, wrist position, grip, and hand-tool use [Fransson-Hall et al. 1995]. Videotape analysis and electromyograms were conducted on a subgroup [Hägg et al. 1996]. A diagnosis of tenosynovitis or peritendinitis required the observation of swelling and pain during active movement on physical examination. A diagnosis of deQuervain's disease required a positive

Finkelstein's test. No cases of tenosynovitis or peritendinitis, other than deQuervain's disease, were found in this study, probably because of strict clinical criteria used for the case definition. The PR for deQuervain's disease among the automobile assembly line workers was 2.49 (95% CI 1.00–6.23) compared to the general population group. Psychosocial variables and other potential confounders or effect modifiers were addressed by Fransson-Hall et al. [1995]. A higher prevalence of deQuervain's disease was noted among men than women.

Kurppa et al. [1991] conducted a prospective cohort study of tenosynovitis or peritendinitis (and epicondylitis) in a meat processing factory in Finland. Three hundred seventy-seven meatcutters, meatpackers, and sausage makers were compared to 338 office workers, maintenance workers, and supervisors. Exposure assessment was based on previously published literature and knowledge of jobs at the plant. Job categories were selected based on whether or not strenuous manual work was required. The cohort was followed for 31 months. Health assessment consisted of physical examinations by plant physicians who were on-site daily, using predetermined criteria for diagnosing tenosynovitis or peritendinitis (swelling or crepitation and tenderness to palpation along the tendon and pain at the tendon sheath, in the peritendinous area, or at the muscle-tendon junction during active movement) and deQuervain's disease (positive Finkelstein's test). Incidence density rates (if a recurrence of tendinitis occurred after 60 days, it was considered a new case) for tendinitis were compared between each of the strenuous job categories and either the male or female comparison group of combined non-strenuous job categories (office workers, maintenance workers and supervisors). The RR for tendinitis among the meatcutters (100% males) compared to the male comparison group was 14.0 (5.7, 34.4); the RR for tendinitis among the meatpackers (79% female) compared to the female comparison group was 38.5 (11.7, 56.1); and the risk ratio for tendinitis among the sausage makers (86% female) was 25.6 (19.2, 77.5). A limitation of the study is the fact that the subjects were not actively evaluated for musculoskeletal disorders. Investigators relied on workers to seek medical care. This could result in a difference in case ascertainment between the exposed and unexposed groups because workers in non-strenuous jobs may not have sought medical care for musculoskeletal disorders since they might still be able to perform their jobs, whereas workers with MSDs in strenuous jobs might not be able to perform their jobs, and would be more likely to seek medical care. If subjects sought medical care, investigators were very likely to capture the information, even if medical care was provided outside the plant, plant nurses received and reimbursed the bills, and recorded the diagnosis and sick leave. However, when diagnoses were made by physicians outside the plant, diagnostic criteria were unknown; this occurred in 25% of the cases. Exposed and comparison groups were similar in age and gender mix, although gender varied with job.

McCormack et al. [1990] studied tendinitis and related disorders of the upper extremity among 1,579 textile production workers compared to 468 referents that included machine maintenance workers, transportation workers, cleaners, and sweepers. The textile production workers

were reported, based on knowledge of the jobs to be exposed to repetitive finger, wrist and elbow motions; no formal exposure assessment was conducted. Health assessment included a questionnaire and screening physical examination followed by a diagnostic physical examination. The diagnosis of tendinitis required positive physical findings suggestive of inflammation. The textile production workers were divided into four broad job categories. Boarding (n=296), was the only category noted to require forceful work. The PR for tendinitis among the boarding workers was 3.0 (95% CI 1.4–6.4), compared to the reference group. Race and age were not related to outcome, but the prevalence of tendinitis was higher in workers with less than three years of employment. Female gender was a significant predictor of tendinitis (p=0.01), but job category was a stronger predictor (p=0.001).

Roto and Kivi [1984] studied the prevalence of tenosynovitis among 92 male meatcutters compared to 72 male construction foremen. No formal exposure assessment was conducted. Meatcutters' work entailed repetitive physical exertion of upper extremities and shoulders. Construction foremen's work did not involve repetitive movements of the upper extremities. Health assessment was by questionnaire and physical examination. Tenosynovitis was defined as swelling, local pain, and finger weakness during movement. The prevalence of tenosynovitis among the meatcutters was 4.5%. The PR for tenosynovitis as defined by physical examination could not be calculated because there were no cases among the comparison group. The PR of tendinitis-like symptoms reported on the questionnaire among the meatcutters was 3.09 (1.43, 6.67) compared to the construction foremen. Serologic testing for rheumatoid arthritis was done to control for potential confounding, none was detected. Authors noted that tenosynovitis occurred in younger age groups.

Strength of Association—Force and Hand/Wrist Tendinitis

Estimates of RR for hand/wrist tendinitis among those in jobs requiring forceful exertion range from 2.5 to 38.5:

The very large risk ratios reported by Kurppa et al. [1991] could be biased upward because of the difference in case ascertainment between the exposed and unexposed groups. Investigators did not actively evaluate subjects for MSDs, but relied on workers to seek medical care. As the authors noted, workers in non-strenuous jobs may not have sought medical care for MSDs since they might still be able to perform their jobs, while workers in strenuous jobs may not have been able to perform their jobs and would be more likely to seek medical care. This potential for differential case ascertainment between the exposed and unexposed groups undermines the credibility of the magnitude of the risk estimate.

Statistically significant estimates of RR for hand/wrist tendinitis among workers who perform strenuous tasks from the remaining studies range from 2.5 to 3.1.

Force and Hand/Wrist Tendinitis

PR and 95% CI	Authors	Exposed/Unexposed Groups
4.8 (0.6–39.7) 17.0 (2.1–26.2)	Armstrong et al. [1987a]	HI FORCE & LO REP/LO FORCE & LO REP HI FORCE & HI REP/ LO FORCE & LO REP
2.5 (1.0–6.23)	Byström et al. [1995]	Auto assemblers/general population
14.0 (5.7–34.4) to 38.5 (11.7–56.1)	Kurppa et al. [1991]	Meat processors/office workers, maintenance workers, supervisors
3.0 (1.4–6.4)	McCormack et al. [1990]	Textile boarding workers/ maintenance workers, etc.
3.1 (1.4–6.7)	Roto and Kivi [1984]	Meatcutters/construction foremen

* Study met all four criteria.

Temporal Relationship—Force and Hand/Wrist Tendinitis

The Kurppa et al. [1991] study determined exposure status of 83% of the cohort on October 2, 1982, and followed their health status until April 30, 1985. The remaining subjects entered the study when they became permanent employees, and were also followed until April 30, 1985.

Although the remaining studies that addressed force were cross-sectional, the following information increases the likelihood that exposure to forceful work occurred before the occurrence of tendinitis; Byström et al. [1995] noted that subjects were selected for clinical examination
5 months after completion of questionnaires on exposure. McCormack et al. [1990] reported that the minimum average length of employment in the job categories studied was more than 7 years. Roto and Kivi's

[1984] subjects had all worked in the food industry for more than one year. Armstrong et al. [1987a] required a minimum of 1 year of employment to be included in the study.

Consistency of Association—Force and Hand/Wrist Tendinitis

All of the studies reviewed reported positive RR estimates for hand/wrist tendinitis among occupational groups exposed to forceful exertions, ranging from 1.8 to 38.5. Four of the five studies reported statistically significant findings. If only statistically significant estimates from studies in which limitations were not noted are considered, RR estimates for force and hand/wrist tendinitis range from 2.5 to 3.1.

Coherence of Evidence—Force and Hand/Wrist Tendinitis

See Repetition Section.

Evidence of a Dose-Response Relationship—Force and Hand/Wrist Tendinitis

Armstrong et al. [1987a] demonstrated a dose-response relationship between jobs requiring forceful exertions and hand/wrist tendinitis. The estimate of RR for hand/wrist tendinitis among workers with jobs that were classified as HIGH FORCE & LOW REPETITION was 4.8 (0.6, 39.7), while the estimate for HIGH FORCE & HIGH REPETITION jobs was 17.0 (2.3, 126.2), compared to the comparison group of LOW FORCE & LOW REPETITION jobs.

Conclusions on Force and Hand/Wrist Tendinitis

There is **strong evidence** for an association between work that requires forceful exertions, in combination with other job risk factors, and hand/wrist tendinitis based on currently available epidemiologic data. All five of the studies reviewed reported data that resulted in positive RR estimates. Four of the five estimates were statistically significant. Eliminating one estimate of RR from a study with noted limitations that might bias the estimate upward does not change this conclusion. Potential confounders such as age and gender were examined in these studies (see discussion of potential confounders on page 5b-16) and there was no evidence that reported associations were distorted by confounders.

POSTURE

Definition of Posture for Hand/Wrist Tendinitis

Kuorinka and Koskinen [1979] determined the time spent in deviated wrist postures per work cycle as part of their "workload index" that was used in a dose-response analysis

within the exposed group. Comparison groups in the other studies were job categories; selection of the groups to be compared was based on observations, questionnaire data, or surveillance data.

Studies Reporting on the Association of Posture and Hand/Wrist Tendinitis

Four studies addressed posture: Amano et al. [1988]; Byström et al. [1995]; Luopajärvi et al. [1979]; and Kuorinka and Koskinen [1979].

Studies Meeting the Four Criteria

Luopajärvi et al. [1979] met all four evaluation criteria. Luopajärvi et al. [1979] compared the prevalence of hand/wrist tendinitis among 152 female assembly line packers in a food production factory to 133 female shop assistants in a department store. Exposure to repetitive work, awkward hand/arm postures, and static work was assessed by observation and videotape analysis of factory workers. No formal exposure assessment was conducted on the department store workers; their job tasks were described as variable. Cashiers were excluded, presumably because their work was repetitive. The health assessment consisted of interviews and physical examinations conducted by a physiotherapist (active and passive motions, grip-strength testing, observation, and palpation); and diagnoses of tenosynovitis and peritendinitis were later determined by medical specialists using these findings and predetermined criteria. The PR for tendinitis among the assembly line packers compared to the shop assistants was 4.13 (95% CI

2.63–6.49). Age, hobbies, and housework were addressed, and no associations with musculoskeletal disorders were identified.

Studies Meeting at Least One Criteria

Amano et al. [1988] reported the prevalence of cervicobrachial disorders, including tenosynovitis, among 102 assembly line workers in an athletic shoe factory and 102 age- and gender-matched non-assembly line workers (clerks, nurses, telephone operators, cooks, and key punchers). Exposure assessment was based on videotape analysis of the tasks of 29 workers on one assembly line. Characteristic basic postures were summarized by the investigators as: holding a shoe or a tool, extending or bending the arms, and keeping the arms in a certain position. Assembly line workers produced about 3,400 shoes a day. All but one task had cycle times less than 30 seconds. No formal exposure assessment of the comparison group was reported. Diagnoses were determined by physical examination, including palpation for tenderness. The PRs for tenosynovitis of the right and left index finger flexors among the shoe factory workers were 3.67 (95% CI 1.85–7.27) and 6.17 (95% CI 2.72–13.97) respectively, compared to the non-factory workers. Tenosynovitis of the other digits was not diagnosed in the comparison group. Shoe assembly workers held shoe lasts longer in the left hand and had greater frequency of symptoms in the left hand. Comparison subjects were matched to shoe factory workers on gender and age (within five years).

Byström et al. [1995] studied forearm and hand disorders among 199 automobile assembly line workers and compared them to 186 randomly selected subjects from the general Swedish population. For both groups, exposure was assessed using rating scales on nurse-administered questionnaires that addressed daily duration of hand and

finger movements, wrist position, grip, and hand-tool use [Fransson-Hall et al. 1995]. Videotape analysis and electromyograms were conducted on a subgroup [Hägg et al. 1996]. A diagnosis of tenosynovitis or peritendinitis required the observation of swelling and pain during active movement on physical examination. A diagnosis of deQuervain's disease required a positive Finkelstein's test. No cases of tenosynovitis or peritendinitis, other than deQuervain's disease, were found in this study, probably because of strict clinical criteria used for the case definition. The PR for deQuervain's disease among the automobile assembly line workers was 2.49 (95% CI 1.00–6.23) compared to the general population group. Psychosocial variables and other potential confounders or effect modifiers were addressed by Fransson-Hall et al. [1995]. A higher prevalence of deQuervain's disease was noted among men than women.

Kuorinka and Koskinen [1979] studied occupational rheumatic diseases and upper limb strain among 93 scissor makers and compared them to the same group of department store assistants (n=143) that Luopajärvi used as a comparison group. Temporary workers and those with recent trauma were excluded from the scissor makers group. Exposure assessment included videotape analysis of scissor maker tasks. The time spent in deviated wrist postures per work cycle was multiplied by the number of pieces handled per hour and the number of hours worked to create a workload index. Cycle times ranged from 2 to 26 seconds; the number of pieces handled per hour ranged from 150 to 605. No formal exposure assessment was conducted on the shop assistants. Health assessment involved interview and physical examination by a

physiotherapist following a standard protocol. Diagnoses of tenosynovitis and peritendinitis were later determined from these findings using predetermined criteria (localized tenderness and pain during movement, low-grip force, swelling of wrist tendons [Waris et al. 1979]). In equivocal cases, orthopedic and physiatric teams determined case status. The PR for muscle-tendon syndrome among the scissor makers as 1.38 (95% CI 0.76–2.51) compared to the department store assistants. Whether or not cashiers were excluded from the comparison group in this study, as they were in the Luopajärvi et al. [1979] study is unclear. The study group was 99% female. No relationship was found between age or body mass index and muscle-tendon syndrome. The number of symptoms increased with the number of parts handled per year. Analyses of subgroups of scissor makers showed non-significant increased prevalence of muscle-tendon syndrome in short versus long cycle tasks and in manipulation versus inspection tasks. The authors noted a lack of contrast in exposures between the subgroups. A non-significant trend of increasing prevalence of diagnosed muscle-tendon syndrome with increasing number of pieces handled per year was noted in a nested case-control analysis (n=36).

Strength of Association—Extreme Posture and Hand/Wrist Tendinitis

The PRs for extreme postures and hand/wrist tendinitis ranged from 1.4 to 6.2. All of the PRs were greater than one and three of the four studies reported statistically significant estimates. As noted in the Repetition Section, the possibility of examiner bias might exist in the study reported by Amano et al. [1988], potentially biasing the RR estimate upward. The middle of the range of statistically significant estimates for RR for hand/wrist tendinitis is 2.5 to 4.1.

Temporal Relationship

Although all of the studies reviewed in this section were cross-sectional, at least two of the studies addressed temporality by reporting a minimum length of employment (Luopajärvi et al. [1979]—5 years) or by evaluating exposure before health outcomes [Byström et al. 1995], as discussed in the previous sections on Repetition and Force.

Consistency

All of the studies reviewed showed positive RR estimates for hand/wrist tendinitis among occupational groups exposed to extreme postures, ranging from 1.4 to 6.2. Three of the four studies reviewed resulted in statistically significant PRs. Considering only statistically significant estimates from studies not noted to have design limitations that might bias the RR, narrows the range to 2.5 to 4.1.

Coherence of Evidence

See Repetition Section.

Dose-Response

See Repetition Section.

Posture and Hand/Wrist Tendinitis

PR and 95% CI	Authors	Exposed/Unexposed Groups
4.1 (2.6–6.5)	Luopajärvi et al. [1979]	Food packers/department store assistants
3.7 (1.9–7.3) to 6.2 (2.7–14.0)	Amano et al. [1988]	Shoe assemblers/clerks, nurses, operators, cooks, keypunchers
2.5 (1.0–6.23)	Byström et al. [1995]	Auto assemblers/general population
1.4 (0.8–2.5)	Kuorinka and Koskinen [1979]	Scissor makers/department. store assistants

There is **strong evidence** for a positive association between work that requires extreme postures, in combination with other job risk factors, and hand/wrist tendinitis, based on currently available epidemiologic data. All of the studies reviewed reported data that resulted in positive RR estimates. Three of the four estimates from these studies were statistically significant. Taking into account the effect of potential confounders (See Repetition Section) such as gender, age, and study limitations does not alter this conclusion.

Potential Confounders

Gender

The association between gender and tendinitis is not uniform. Byström et al. [1995] reported a higher prevalence of deQuervain's tendinitis in men than in women, and proposed the explanation that men in their study group used hand tools more often than women. Ulnar deviation and static muscle loading were likewise more often reported among men. Armstrong et al. [1987a] reported a higher prevalence of tendinitis among women but found no significant associations with other medical factors or activities outside of work. However, significant differences in posture were observed between males and females. Differences in postures may be due to differences in height between men and women whose workstations have uniform dimensions. In McCormack et al.'s [1990] study of textile workers, three of the four exposed groups were largely female (89%–95%), limiting the ability to separate the effect of gender from job effect. However, in an analysis that included gender and job as risk factors, they reported that gender was a significant predictor of tendinitis (p=0.01), but not as significant a predictor as job category (p=0.001). The other studies reviewed did not have both male and female subjects.

Age

Several investigators noted that tendinitis appears to be more prevalent in younger age groups. Byström et al. [1995] reported that most of the cases of deQuervain's tendinitis occurred in the <40-yr age group.

McCormack et al. [1990] reported that age was not a significant predictor of tendinitis, but years on the job was inversely associated—prevalence was higher if less than 3 years on the job. Armstrong et al. [1987] noted that “a significant interaction between sex, age, and years on the job suggested that the risk of hand/wrist tendinitis might actually decrease with an increased number of years on the job, but the effect was too small to merit further discussion.” Roto and Kivi [1984] noted that “The few cases of tenosynovitis occurred in younger workers.” Kuorinka and Koskinen [1979] and Luopajärvi et al. [1979] found no significant association between age and tendinitis.

Other Potential Confounders

McCormack et al. [1990] reported that race was not associated with tendinitis. Armstrong et al. [1987a] found no significant associations with personal factors—birth control pills, hysterectomy, oophorectomy, recreational activities. No subjects with seropositive rheumatic diseases were included in the Kuorinka and Koskinen [1979] study. They reported that their earlier unpublished questionnaire found no correlations between illness and extra work, work outside the factory, work at home, or hobbies. Luopajärvi et al. [1979] excluded subjects with previous trauma, arthritis, and other pathologies.

There is no evidence in the studies reviewed here that the associations reported between work factors and hand/wrist tendinitis are explained by gender, age, or other factors.

CONCLUSIONS

Eight epidemiologic studies have examined physical workplace factors and their relationship to hand/wrist tendinitis. Several studies fulfill the four epidemiologic criteria that were used in this review, and appropriately address important methodologic issues. The studies generally involved populations exposed to a combination of work factors; one study assessed single work factors such as repetitive motions of the hand. We examined each of these studies, whether the findings were positive, negative, or equivocal, to evaluate the strength of work-relatedness, using causal inference.

There is **evidence** of an association between any single factor (repetition, force, and posture) and hand/wrist tendinitis, based on currently available epidemiologic data. There is **strong evidence** that job tasks that require a combination of risk factors (e.g., highly repetitious, forceful hand/wrist exertions) increase risk for hand/wrist tendinitis.

Table 5b-1. Epidemiologic criteria used to examine studies of hand/wrist tendinitis associated with repetition

Study (first author and year)	Risk indicators (OR, PRR, IR or *p*-value)[*,†]	Participation rate $\geq$70%	Physical examination	Investigator blinded to case and/or exposure status	Basis for assessing hand/wrist exposure to repetition
Met all four criteria:					
Armstrong 1987a	5.5, 17.0[†]	Yes	Yes	Yes	Observation or measurements
Luopajärvi 1979	4.1[†]	Yes	Yes	Yes	Observation or measurements
Met at least one criterion:					
Amano 1988	3.7–6.2[†]	NR[‡]	Yes	NR	Job titles or self-reports
Byström 1995	2.5[†]	Yes	Yes	No	Job titles or self-reports[§]
Kuorinka 1979	1.4	Yes	Yes	NR	Observation or measurements
McCormack 1990	1.8	Yes	Yes	NR	Job titles or self-reports
Roto 1984	3.1[†]	Yes	Yes	Yes	Job titles or self-reports

[*]Some risk indicators are based on a combination of risk factors—not on repetition alone (i.e., repetition plus force, posture, or vibration). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

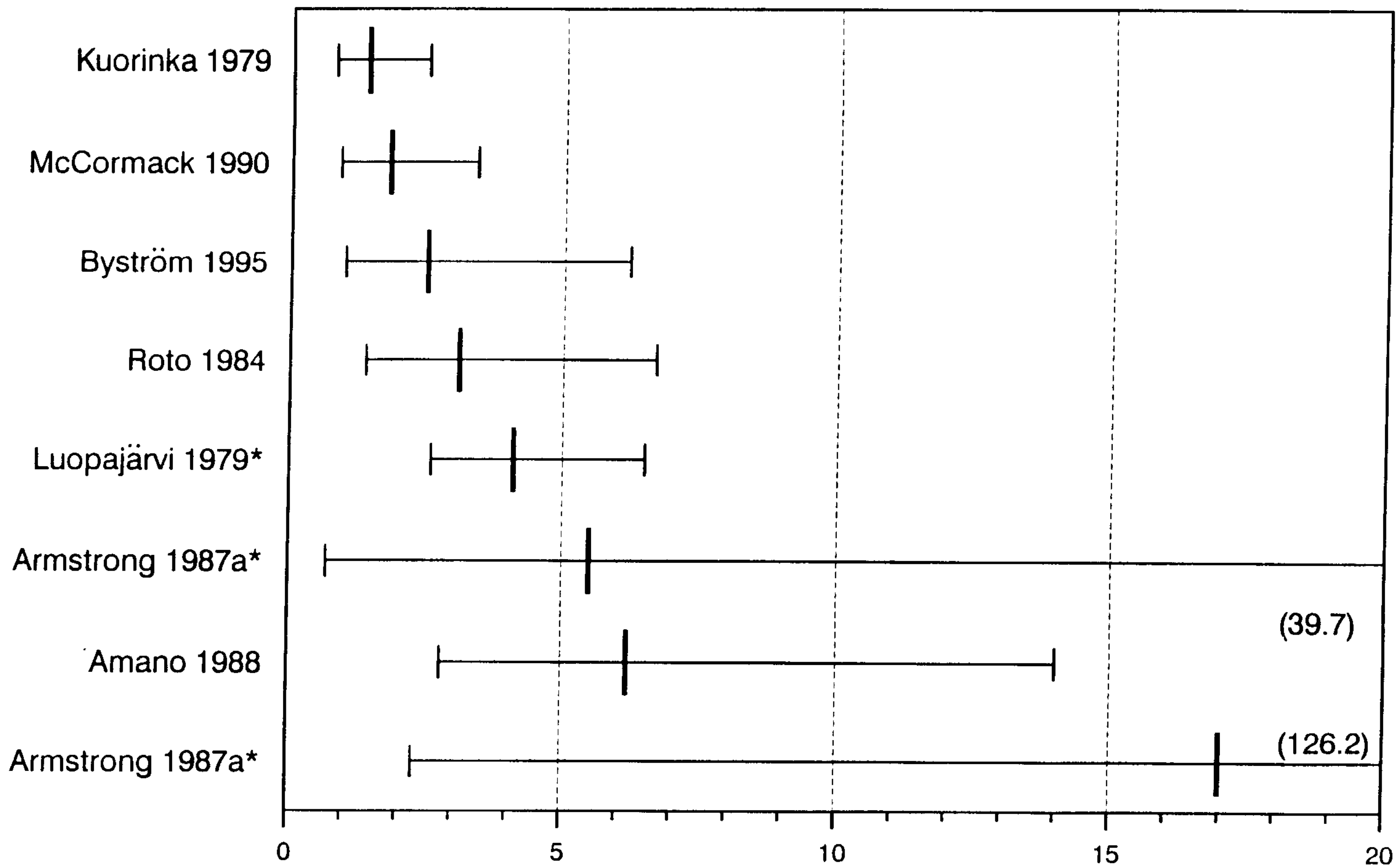
[†]Indicates statistical significance.

[‡]Not reported.

[§]EMG and video analysis of subgroup reported in Hägg et al. [1996].

Figure 5b-1. **Risk Indicator for "Repetition" and Hand/Wrist Tendinitis**

(Odds Ratios and Confidence Intervals)



* Studies which met all four criteria.

Table 5b-2. Epidemiologic criteria used to examine studies of hand/wrist tendinitis MSDs associated with force

Study (first author and year)	Risk indicator (OR, PRR, IR or *p*-value)*,†	Participation rate $70%	Physical examination	Investigator blinded to case and/or exposure status	Basis for assessing hand/wrist exposure to force
Met all four criteria:					
Armstrong 1987a	17.0†, 4.8	Yes	Yes	Yes	Observation or measurements
Met at least one criterion:					
Byström 1995	2.5†	Yes	Yes	No	Job titles or self-reports§
Kurppa 1991	14.0–38.5†	Yes	Yes	NR‡	Observation or measurements
McCormack 1990	3.0†	Yes	Yes	NR	Job titles or self-reports
Roto 1984	3.1†	Yes	Yes	Yes	Job titles or self-reports

*Some risk indicators are based on a combination of risk factors—not on force alone (i.e., force plus repetition, posture, or vibration). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

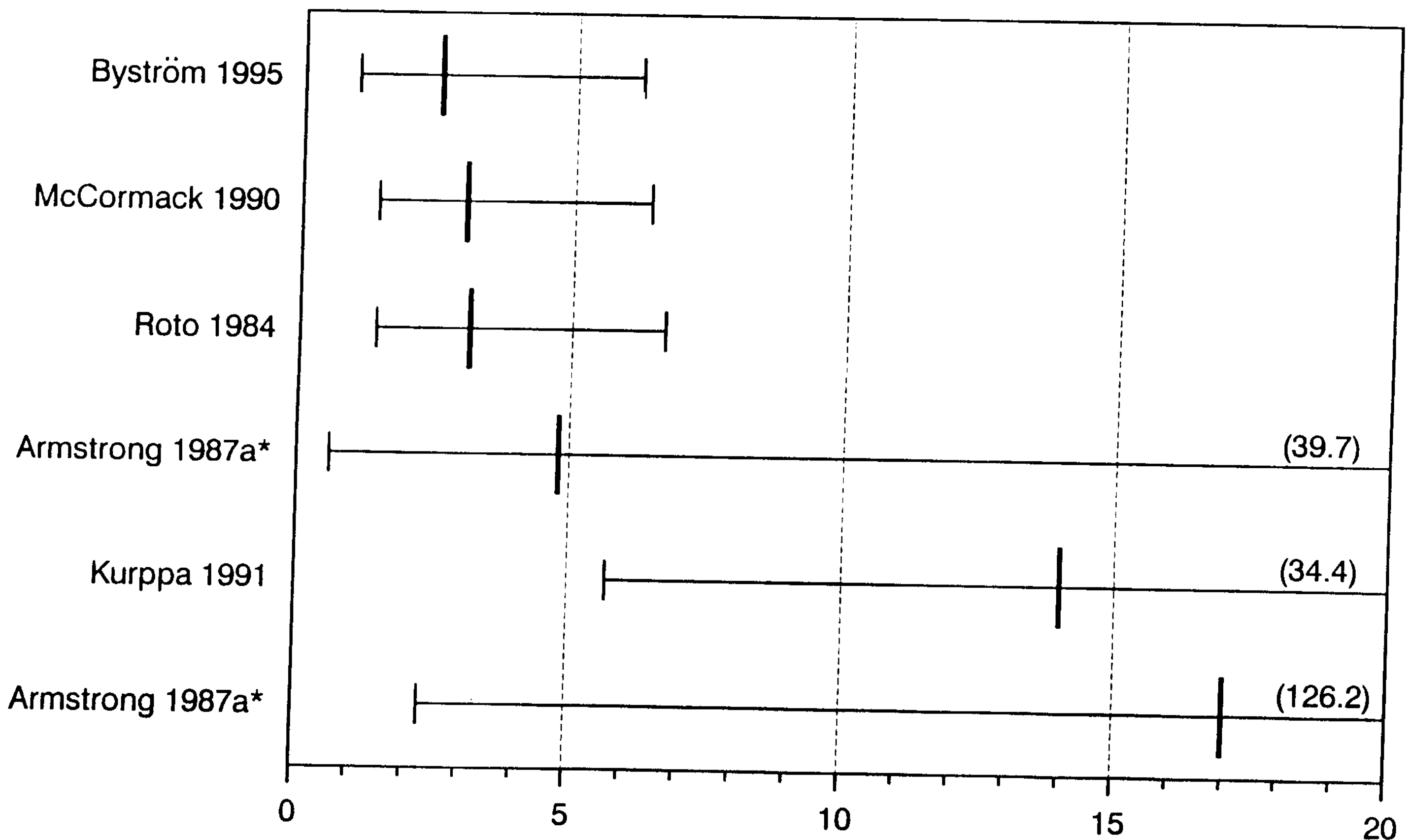
†Indicates statistical significance.

‡Not reported.

§EMG and video analysis of subgroup reported in Hägg et al. [1996].

Figure 5b-2. **Risk Indicator for "Force" and Hand/Wrist Tendinitis**

(Odds Ratios and Confidence Intervals)



* Studies which met all four criteria.

Table 5b-3. Epidemiologic criteria used to examine studies of hand/wrist tendinitis MSDs associated with posture

Study (first author and year)	Risk indicator (OR, PRR, IR or *p*-value)[*,†]	Participation rate ≥70%	Physical examination	Investigator blinded to case and/or exposure status	Basis for assessing hand/wrist exposure to posture
Met all four criteria:					
Luopajärvi 1979	4.1[†]	Yes	Yes	Yes	Observation or measurements
Met at least one criterion:					
Amano 1988	3.7–6.2[†]	NR[‡]	Yes	NR	Job titles or self-reports
Byström 1995	2.5[†]	Yes	Yes	No	Job titles or self-reports[§]
Kuorinka 1979	1.4	Yes	Yes	NR	Observation or measurements

[*]Some risk indicators are based on a combination of risk factors—not on posture alone (i.e., posture plus force, repetition, or vibration). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

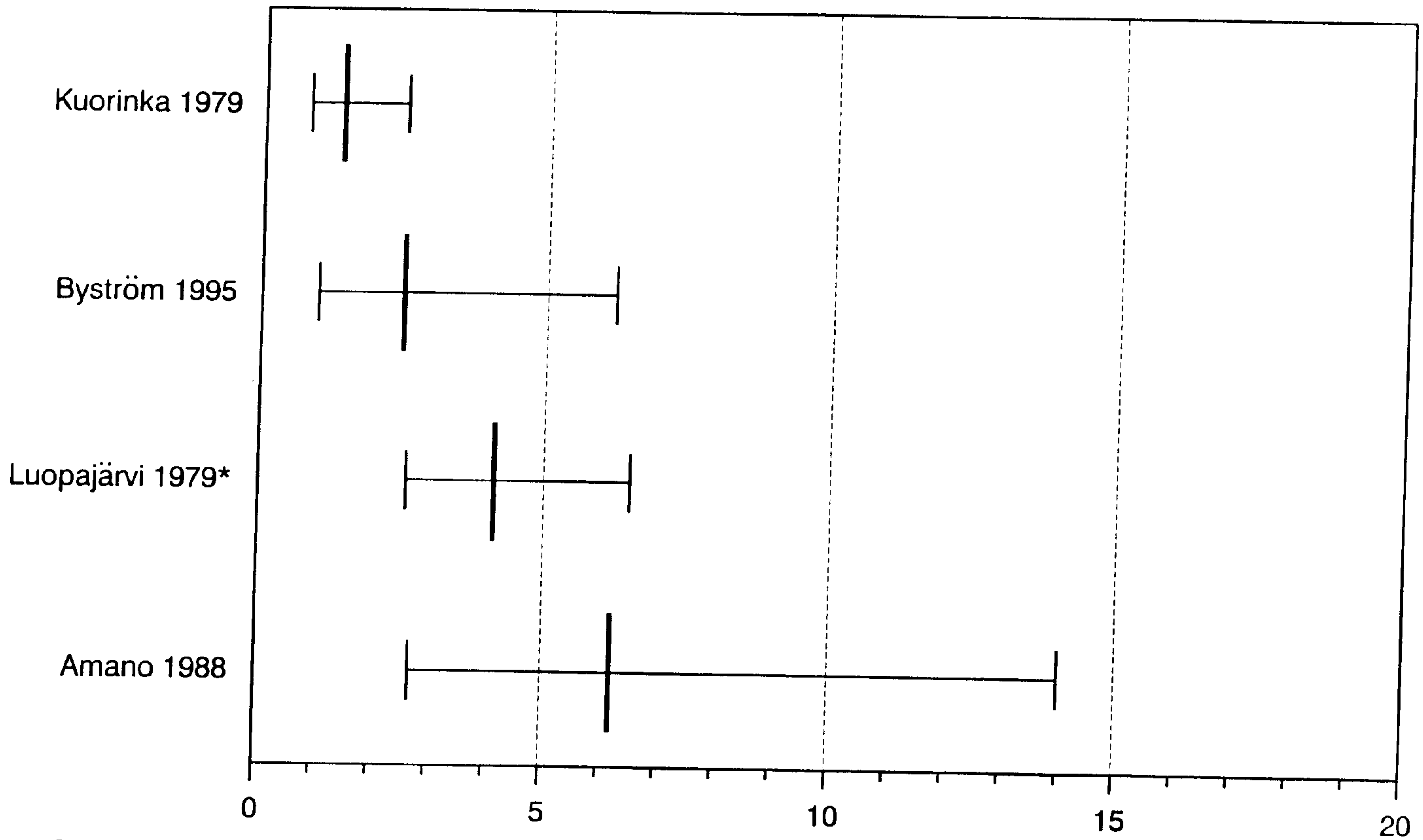
[†]Indicates statistical significance.

[‡]Not reported.

[§]EMG and video analysis of subgroup reported in Hägg et al. [1996].

Figure 5b-3. **Risk Indicator for "Posture" and Hand/Wrist Tendinitis**

(Odds Ratios and Confidence Intervals)



* Studies which met all four criteria.

Table 5b–4. Epidemiologic studies evaluating work-related hand/wrist tendinitis

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Amano et al. 1988	Cross-sectional	102 assembly line workers in an athletic shoe factory compared to 102 age and gender matched non-assembly line workers (clerks, nurses, telephone operators, cooks, and key punchers).	Outcome: Examination by a physician: palpation for tenosynovitis and tenderness. Exposure: One line of 29 shoe assembly workers was selected for job analysis. Videotapes were evaluated for movements of the upper extremities and shoulders and cycle and holding times. No formal exposure assessment of comparison group.	Tenosynovitis, right index finger flexors: 32.35% Tenosynovitis, left index finger flexors: 36.27%	Tenosynovitis right index finger flexors: 8.82% Tenosynovitis left index finger flexors: 5.88%	PRR=3.67 PRR=6.17	1.85-7.27 2.72-13.97	Participation rate: Not reported. Unclear whether examiner was blinded to job category (occupational groups examined on separate dates). No clear case definition provided. Potential for examiner bias exists. Comparison group was matched in gender and age (within 5 years). Tenosynovitis of other digits was not diagnosed in the comparison group. Neurological exam and clinical tests of pinch strength, tapping, pressure, and vibration sensibility were also done. No significant differences between groups in finger-pinch strength. Shoe workers failed the tapping test more often, had lower pressure-sensibility in 1 of 10 fingers tested, and had lower vibration-sensibility in 2 of 10 fingers. One of 3 neurological maneuvers (Morley's test) was more often positive in shoe workers. Exposure to toluene is noted and is a potential confounder for neurological findings. Assembly line workers produced about 3,400 shoes a day. All but one task had cycle times <30 sec. Assembly workers held shoe lasts longer in the left hand and had greater frequency of symptoms in left hand vs. non-assembly workers, who were assumed to use right hand (dominant hand) more frequently.

(Continued)

Table 5b–4 (Continued). Epidemiologic studies evaluating work-related hand/wrist tendinitis

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Armstrong 1987a	Cross-sectional	652 industrial workers divided into 4 groups: (1) low force, low repetition (comparison group, n=157), (2) high force, low repetition (n=195), (3) low force and high repetition (n=143), and (4) high force and high repetition (n=157).	Outcome: Positive findings on interview and physical exam were required for case definition. Tendinitis/teno-synovitis: localized pain or swelling lasting > a week, and increased pain with resisted but not passive motion. Trigger finger: locking in extension or flexion and a palpable nodule at base of finger. DeQuervain's: positive Finkelstein test with localized pain score of >=4 (range 1 to 8). Exposure: To force and repetition assessed by EMG and video analysis of jobs performed by a sample of workers.	3.1% (Group 2) 3.5% (Group 3) 10.8% (Group 4)	0.6%	PRR=4.8 PRR=5.5 PRR=17.0	0.6-39.7 0.7-46.3 2.3-126.2	Participation rate: 90% of workers originally selected for inclusion actually participated. The effect of age, gender, years on the job, and plant were analyzed. Higher prevalence of tendinitis among women, but not significantly associated with personal factors. Significant differences in posture were observed between males and females. Examiners were blinded to exposure status of study participants.

(Continued)

Table 5b–4 (Continued). Epidemiologic studies evaluating work-related hand/wrist tendinitis

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Byström et al. 1995	Cross-sectional	199 automobile assembly line workers, compared to 186 general population.	Outcome: Tenosynovitis or peri-tendinitis were diagnosed based on physical examination observations: swelling and pain at the tendon sheath, peritendinous area or muscle-tendon junction during active movement of the tendon. deQuervain's tendinitis: Positive Finkelstein's test. Exposure: Daily duration of hand and finger movements, manual handling, wrist position, grip type, and hand-tool use were rated by workers on 6-point scales in questionnaires [Fransson-Hall et al. 1995]. Forearm muscular-load and wrist angle were evaluated by EMG and videotape analysis for a subgroup [Hägg et al. 1996].	8.04% (deQuervain's tendinitis)	3.23%	PRR=2.49	1.00-6.23	Participation rate: 96%. Study group randomly selected from assembly division of a plant. Comparison group is from the MUSIC study [Hagberg and Hogstedt 1991]. Examiners blinded to exposure status: no, everyone examined by the authors was in the exposed group. Results are reported separately for males and females, and for age <40 years. Psychosocial variables and other potential confounders or effect modifiers were addressed by Fransson-Hall et al. [1995]. Higher prevalence of deQuervain's tendinitis in males than in females—possibly related to greater use of hand tools, ulnar deviation, and/or static muscle loading. No cases of tenosynovitis or peritendinitis were found in this study, probably because of strict clinical criteria (required observation of swelling).

(Continued)

Table 5b–4 (Continued). Epidemiologic studies evaluating work-related hand/wrist tendinitis

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	Referent group	RR, OR, or PRR	95% CI	Comments
Kuorinka and Koskinen 1979	Cross-sectional	93 scissor makers compared to 143 shop assistants. Phase One: physical examination and interview. Phase Two: work analysis. 10-month interval between phases. Comparison group was from another study that used the same method [Luopajärvi et al. 1979].	Outcome: Tenosynovitis and peritendinitis diagnosed by interview and physical exam. Physiotherapist examined workers, diagnoses were from predetermined criteria [Waris 1979] (localized tenderness and pain during movement and low grip-force and swelling of wrist tendons). In problem cases orthopedic and physiatric teams determined case status. Exposure: Work history, hr, and production rates for the previous year were taken from company records. A workload index was based on videotape analysis of scissor maker workstations: time spent in deviated wrist-posture (>20E)/work cycle; multiplied by number pieces handled multiplied by hr worked. No exposure assessment of shop assistants.	18.3%	13.5%	PRR=1.38	0.76-2.51	Participation rate: 81%. Examiner was not blinded to case status, but diagnosis was made separately, using predetermined criteria [Waris et al. 1979]. Study group was 99% female. No relationship found between age or body mass index and “muscle-tendon syndrome.” The number of symptoms increased with the number of parts handled/year. Workers were paid by piece rate. Within the group of scissor makers, non-significant increased prevalences of muscle-tendon syndrome in short vs. long cycle tasks and in manipulation vs. inspection tasks was reported. The authors noted a lack of contrast in exposures between the subgroups. A non-significant trend of increasing prevalence of diagnosed muscle-tendon syndrome with increasing number of pieces handled/year was noted in a nested case-control analysis (n=36).

(Continued)

Table 5b–4 (Continued). Epidemiologic studies evaluating work-related hand/wrist tendinitis

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Kurppa et al. 1991	Cohort: 31-month follow-up	377 meatcutters, meatpackers and sausage makers compared to 388 office workers, maintenance workers, and supervisors.	Outcome: Defined as physician-diagnosed tenosynovitis or peritendinitis of the hand or forearm. Criteria were swelling or crepitation and tenderness to palpation along the tendon and pain at the tendon sheath, in the peritendinous area, or at the muscle-tendon junction during active movement of the tendon. deQuervain's tendinitis: positive Finkelstein's test (if not positive, included in tendinitis group). 25% of diagnoses made by physicians outside plant, criteria unknown. Exposure: Job categories selected based on whether or not strenuous manual work was required. Exposure data obtained from previous published literature and plant walk-throughs.	12.5/100 person years (meatcutters) 25.3/100 person years (meat-packers) 16.8/100 person years (sausage makers)	0.9/100 person years (males) 0.7/100 person years (females)	14 (meat-cutters) 38.5 (meat-packers) 25.6 (sausage makers)	5.7-34.4 11.7-56.1 19.2-77.5	Participation rate: >70%. Job transfers and employee termination followed up with questionnaire. Questionnaire response rate over 70%. Exposed and comparison groups were similar in age and gender mix, although gender varied with job. If same diagnosis occurred at same site in worker after 60 days, it was considered new episode. Therefore, separate episodes may be recurrences, and thus influence results. Median interval of 233 days between episodes. Packers worked in temperatures 8E to 10EC; sausage makers worked in temperatures 8E to 20EC. Examiners were not blinded to occupation of subjects. Plant selected because of high number of reports of musculoskeletal disorders. All permanent workers in meat cutting, sausage making and packing departments were included, after 3 months of work. Case ascertainment: Workers in non-strenuous jobs may not have sought medical care for MSDs since they might still be able to perform their jobs.

(Continued)

Table 5b–4 (Continued). Epidemiologic studies evaluating work-related hand/wrist tendinitis

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Luopajärvi et al. 1979	Cross-sectional	152 female assembly line packers in a food production factory were compared to 133 female shop assistants in a department store. Cashiers were excluded from comparison group.	Outcome: Tenosynovitis and peritendinitis diagnosed by interview and physical exam. Physiotherapist performed active and passive motions, grip strength tests, observation and palpation. Medical specialists used these findings later to diagnose disorders using predetermined criteria [Waris 1979]. Exposure: Exposure to repetitive work, awkward hand/arm postures, and static work assessed by observation and video analysis of factory workers. No formal exposure assessment of shop assistants.	55.9%	13.5%	PRR= 4.13	2.63-6.49	Participation rate: 84%. Workers excluded from participation for previous trauma, arthritis and other pathologies. Examiner blinded to case status: Not stated in article. No association between age and MSDs or length of employment and MSDs. Factory opened only short time. Hobbies and housework were not significantly associated with outcome. Unable to examine effect of job-specific risk factors because of job rotation.

(Continued)

Table 5b–4 (Continued). Epidemiologic studies evaluating work-related hand/wrist tendinitis

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
McCormack et al. 1990	Cross-sectional	Textile workers: 4 broad job categories involving intensive upper extremity use—sewing (n=562), boarding (n=296), packaging (n=369), and knitting (n=352); compared to other non-office workers (n=468), including machine maintenance workers, transportation workers, and cleaners and sweepers.	Outcome: Assessed by questionnaire and screening physical exam, followed by diagnostic physical examination. Tendinitis: Positive physical findings suggestive of inflammation. Severity reported as mild, moderate or severe. Exposure: To repetitive finger, wrist and elbow motions based on knowledge of jobs; no formal exposure assessment performed.	Boarding: 6.4% Sewing: 4.4% Packaging: 3.3% Knitting: 0.9% Overall exposed group: 3.75%	Other non-office: 2.1%	PRR=3.0 PRR=2.1 PRR=1.5 PRR=0.4 PRR=1.75	1.4-6.4 1.0-4.3 0.7-3.5 0.1-1.4 0.9-3.39	Participation rate: 90.5% for screening; 93.6% of those screened went on to complete physical examination. Stratified random sampling within occupational groups. Not mentioned whether examiners blinded to exposure status (job category). Prevalence higher in workers with <3 years of employment. Race and age not related to outcome. Female gender was a significant predictor of tendinitis (p=0.01), but job category was a stronger predictor (p=0.001). 10/12 physician examiners recorded diagnoses within 12% of the mean for the group. 47.9% of workers who had either positive screening physical exams or reported symptoms on questionnaire were diagnosed with tendinitis or tendinitis-related syndromes.

(Continued)

Table 5b–4 (Continued). Epidemiologic studies evaluating work-related hand/wrist tendinitis

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Roto and Kivi 1984	Cross-sectional	90 meatcutters compared to reference group of 72 construction foremen who had not been exposed to repetitive movements of the upper extremities in their work. All participants were male.	Outcome: Tenosynovitis defined as swelling, local pain and finger weakness during movement (determined by questionnaire and physical exam). Exposure: Based on job title. Study groups were selected based on general knowledge of job tasks: meatcutters' work entailed physical exertion of upper extremities and shoulders. Construction foremen's work did not involve repetitive movements of the upper extremities. No formal exposure assessment.	4.5% Symptom prevalence rate: 30.0%	0.0% Symptom prevalence rate: 10.0%	Indetermin-ate PRR=3.09	õ 1.43-6.67	Participation rate: 100% for meatcutters, 94% for comparison group. Authors state that examiners were blinded to occupation of subjects because part of larger group of meat processing workers examined, but it is unclear whether construction foremen (referents) were examined separately. Serologic testing for rheumatoid arthritis was done to control for potential confounding (none detected). Relatively strict diagnostic criteria used to avoid false positive cases. Authors note that tenosynovitis occurred in younger age groups. Although the only diagnosed cases of tenosynovitis occurred in the meatcutters (none in the referents), the authors were reluctant to infer association with meatcutting because of the relatively low prevalence rate (4.5%).

CHAPTER 5c
Hand-Arm Vibration Syndrome

SUMMARY

In general, the studies listed in Table 5c–1 show **strong evidence** of a positive association between high level exposure to hand-arm vibration (HAV) and vascular symptoms of hand-arm vibration syndrome (HAVS). These studies are of workers with high levels of exposures such as forestry workers, stone drillers, stone cutters or carvers, shipyard workers, or platers. These workers were typically exposed to HAV acceleration levels of 5 to 36 m/s². These studies typically were cross sectional studies which examined the relationship between workers with high levels of exposures to HAV with a non-exposed control group. There is substantial evidence that as intensity and duration of exposure to vibrating tools increase, the risk of developing HAVS increases. There also is evidence that an increase in symptom severity is associated with increased exposure. As intensity and duration of exposure are increased, the time from exposure onset and beginning of symptoms is shortened.

As described above, the relationship between vibration exposure and HAVS was evaluated favorably with regard to other epidemiological causality criteria, including consistency and coherency of available information and evidence describing the temporal sequence of exposure and outcome.

INTRODUCTION

The 20 epidemiologic studies discussed in this review were selected according to criteria that appear in the introduction of this document. In our review, we evaluated the studies according to criteria that enabled us to assess the research. These criteria, including adequate participation rate, definition of health outcome by both symptoms and medical exam criteria, blinding of investigators to exposure/outcome status, and independent/objective measure of exposure, also are described in detail in the Introduction.

In reviewing the studies, we gave greatest qualitative weight to those which fulfilled all four of the above criteria. Table 5c-1 (all tables are presented at the end of the chapter) characterizes the 20 reviewed Hand-Arm Vibration studies according to the four evaluation criteria. Full summary descriptions of all the studies appear at the end of the chapter.

In addition to the four criteria we used to evaluate the studies, we determined whether studies demonstrated statistically significant associations between exposure attributes and health outcomes. We also examined whether the observed associations were likely to be caused or substantially influenced by major study flaws, including confounding and selection bias. Some of these limitations are shown in the descriptions of individual studies (Table 5c–2).

We then reviewed and summarized the studies with regard to standard criteria used by epidemiologists to evaluate the causal relationship between a health outcome and an exposure of interest. These criteria included strength of association, temporal relationship, consistency of association, coherence of association, and exposure-response relationships.

In this review, results of each of the studies examined, whether negative, positive, or equivocal, contributed to the pool of data used to make our decision regarding the strength of the causal relationship between HAVS and workplace risk factors. Greater or lesser confidence in the findings reflected the evaluation criteria described above.

Definition of HAV for HAVS

Hand-Arm Vibration is defined as the transfer of vibration from a tool to a worker's hand and arm. The amount of HAV is characterized by the acceleration level of the tool when grasped by the worker and in use. The vibration is typically measured on the handle of tool while in use to determine the acceleration levels transferred to the worker.

EVIDENCE FOR THE WORK-RELATEDNESS OF HAVS

The hazardous effects of occupational exposure to HAV have been discussed in hundreds of studies dating to the work of Loriga in 1911. The composite of vibration-induced signs and symptoms referred to as hand-arm vibration syndrome includes episodic numbness; tingling and blanching of the fingers, with pain in response to cold exposure; and reduction in grip strength and finger dexterity. These signs and symptoms are known to increase in severity as exposure to vibration increases in intensity and duration.

A review of pertinent epidemiologic studies of HAVS has been previously presented [NIOSH 1989]; therefore, Table 5c–2 includes only those studies completed after 1989. Except for a few longitudinal studies of chain sawyers in the United Kingdom, Finland, and Japan, the literature comprises largely cross-sectional studies carried out within an industry. Cross-sectional studies are limited in their ability to ascertain temporal relationships between exposure and outcome. Because results are obtained at only one point in time, the cross-sectional study design also is subject to underassessment of the health outcome (particularly in groups with longer durations of employment and higher participant attrition).

The studies included in this review varied in design and quality of information. Sixteen were cross-sectional in design, and three were prospective cohort in design. One study was both cross-sectional and prospective, including 10 cross-sectional follow-ups over time and a cohort group [Koskimies et al. 1992]. Thirteen of the 20 studies reported assessing case status using physical exams, while other studies used only a questionnaire to determine outcomes. Of the studies in which the subjects underwent a physical exam, five performed a cold provocation test [Bovenzi et al. 1988; Bovenzi et al. 1995; Brubaker et al. 1983; Brubaker et al. 1987; McKenna et al. 1993], three performed a nail compression test [Mirbod et al. 1992b; Nagata et al. 1993; Saito 1987], one performed a nerve conduction test [Virokannas 1995], one performed sensorineural physician testing [Bovenzi and Betta 1994], one performed a neurological exam [Shinev et al. 1992], one performed an Allan test [Nilsson et al. 1989] and one used physician judgement based on workers' complaints and history [Koskimies et al. 1992].

Twelve of the 20 studies conducted an exposure assessment of the tools subjects were using; an additional study used exposure assessment information the authors had collected in a previous investigation. The remaining studies estimated exposures by self-report or job title.

The one study that met all four criteria and the four studies which met the three criteria are discussed in the following section. Detailed descriptions for all 20 investigations can be found at the end of the chapter.

Comments Related to Specific Studies of HAVS

The Bovenzi et al. [1995] cross-sectional investigation of forestry workers compared vibration white finger (VWF) in this group with shipyard worker referents. VWF was diagnosed by symptom report and cold provocation test; vibration exposures were estimated by questionnaire report on frequency of chain saw work and types of saws used, along with direct measurement of vibration produced by 27 antivibration and 3 non-antivibration saws. Daily exposure to saw vibration was estimated by linking the two assessments. The prevalence rates for VWF were 23.4% in forestry workers and 2.6% in shipyard referents [Odds ratio (OR) 11.8, 95% Confidence Interval (CI) 4.5–31.1]. For workers using only antivibration saws, the OR was 6.2 (95% CI 2.3–17.1); for those using non-antivibration saws, the OR was 32.3 (95% CI 11.2–93). A dose-response was observed for VWF and lifetime vibration dose (OR 34.3, 95% CI 11.9–99, for the highest category). Although participation rates were not stated for referents, the participation appeared to be 100% for forestry workers. Authors included 10 retired workers to lessen the problems with selection out of the workforce. Results demonstrated that antivibration saw use was associated with a lower prevalence of VWF.

Koskimies et al. [1992] examined vibration syndrome in a group of forestry workers employed by the National Board of Forestry in Finland. All those employed in one parish participated in a series of 10 cross-sectional studies from 1972 to 1990. Results also were reported for a cohort of 57 individuals who remained in the study from 1972 to 1986. HAVS symptoms were assessed by questionnaire and physical exam criteria. Exposure to chain saw vibration was determined by measurement of front handle acceleration. Cross-sectional analysis results showed a monotonic decrease in prevalence of VWF from 40% in 1972 to 5% in 1990. In the cohort of 57, VWF increased from 30% in 1972 to 35% in 1975. VWF decreased monotonically to approximately 6% in 1986. Over the same time period, modifications of chain saws used by the workers resulted in a decrease in saw vibration acceleration from 14 m/s^2 to 2 m/s^2. The authors attributed the reduction in VWF to saw changes, although exposures and outcomes were never linked for individual workers. Strengths of the study included observation of similar results from the series of cross-sectional analyses and full participation on the part of the 57 subjects. Limitations included failure to assess chain saw exposure measures at the individual level. The study demonstrated the potential for symptom improvement after exposure reduction.

In the Nilsson et al. [1989] cross-sectional study of male pulp mill machine manufacturing employees, VWF was examined in a group of 89 platers and 61 office workers. VWF was ascertained by physical exam and interview. For platers, vibration exposure was assessed by measuring acceleration intensity on a sample of tools and linking results to subjective ratings of exposure time. Current and past exposures were estimated for both platers and office workers (some office workers had experienced exposures in the past). Prevalence for platers with current exposure was 42%, in comparison to 2.3% for office workers with no exposures (OR 85, 95% CI 15–486). When those exposed to vibration (platers plus office workers with previous vibration exposure) were compared to unexposed office workers, prevalences were 40.0% and 2.3% respectively (OR 56, 95% CI 12–269). A dose-response was observed for VWF and years of exposure. The relationships between outcome and exposure, after adjustment for age, were strong. Representativeness of the referent group of office workers could not be determined.

Bovenzi [1994] examined HAVS cross-sectionally in 570 quarry drillers and stone carvers, along with a referent group of polishers and machine operators who were not exposed to hand-transmitted vibration. HAVS was assessed by physician interview, and sensorineural symptoms were staged and graded. Exposure to vibrating tools was assessed by interview and linked to vibration measurements obtained from assessment of a sample of tools. Prevalences of HAVS were 30.2% in the exposed and 4.3% in the unexposed groups (OR 9.33, 95% CI 4.9–17.8). Symptoms of VWF increased with lifetime vibration dose (OR 10.2, 95% CI 4.8–21.6, for the highest category). Study strengths included detailed exposure assessment and modeling of relationships, 100% participation, and a very stable work population. Because of the work population stability, results were unlikely to be influenced by participant attrition.

The Bovenzi et al. [1988] cross-sectional investigation examined VWF in vibration-exposed stone drillers and stone cutters/chippers and a reference group of quarry and mill workers. VWF was assessed by questionnaire and physical exam. Exposure was assessed by measuring acceleration intensity on a sample of tools and linking it with self-reported exposure time. VWF prevalence rates were 35.5% in exposed and 8.3% in unexposed groups (OR 6.06, 95% CI 2.0–19.6; OR 4.26, 95% CI 1.8–10.4). A significant association was observed between vibration acceleration level and severity of VWF symptoms (0% and 18.4% in the lowest and highest categories, respectively).

Strength of Association

One of the studies examined met all four of the evaluation criteria [Bovenzi et al. 1995]. Five investigations met three of the criteria [Bovenzi et al. 1988, 1994; Kivekäs et al. 1994; Koskimies et al. 1992; and Nilsson et al. 1989]. The criterion that was not met (or not reported) by four of the studies was blinding of the physician with regard to worker job status. However, most studies used objective measures for determining case status: cold provocation [Bovenzi et al. 1988, 1995], sensorineural physician grading [Bovenzi and the Italian Study Group 1994], and the Allan test [Nilsson et al. 1989]. Use of objective measures lessens the likelihood that case status was influenced by knowledge of participants' exposures.

In the Bovenzi et al. [1988] cross-sectional investigation, vibration-exposed stone drillers and stone cutters/chippers showed a 6.06-fold (95% CI 2.0–19.6) increase in risk of VWF in comparison to unexposed quarry and mill workers. Similar results were observed in another study of stone workers conducted by Bovenzi in 1994. Quarry drillers and stone carvers exposed to vibration showed an OR for VWF of 9.33 (95% CI 4.9–17.8) when compared to a reference group of polishers and machine operators. A dose-response relationship was observed for VWF and lifetime vibration dose, with an OR of 10.2 (95% CI 4.8–21.6) for the highest exposure category. A study of forestry workers [Bovenzi et al. 1995] demonstrated an OR of 11.8 (95% CI 4.5–31.1) for VWF when comparing forestry workers with exposure to chain saw vibration to an unexposed group of shipyard workers. A lower risk of VWF (OR 6.2, 95% CI 2.3–17.1) was observed for those using only antivibration saws. A dose-response between VWF and vibration exposure also was observed in this investigation, with an OR of 34.3 (95% CI 11.9–99) for the highest exposure category. Nilsson et al. [1989] observed very strong relationships between VWF and exposure to vibration in machine manufacturing platers. In comparison to office workers with no exposure, platers had an OR of 85 (95% CI 15–486). Kivekäs et al. [1994] found a significantly increased OR in the cumulative incidence of HAVs in a 7-year cohort study (OR 6.5, 95% CI 2.4–17.5). Koskimies et al. [1992] examined a dynamic cohort of forestry workers at 10 intervals from 1972 to 1990 during which time saws were being modified in weight, vibration frequency, and vibration acceleration. Over the 18-year period, a monotonic decrease in VWF was observed in the 10 cross-sectional examinations, with an overall eight-fold reduction in prevalence. A subset of workers followed from 1972 to 1986 showed a decrease in VWF from 30% to 6%. The reductions were attributed to modifications in chain saws during the same time period.

The remaining, less rigorous, studies showed varying relationships between HAVS and exposure. The majority of the studies demonstrated moderate to strong positive associations. Most compared exposed to unexposed groups with little or no detailed analysis by exposure level. Two investigations examined HAVS in exposed groups and found an increase in risk by years of employment, with ORs of 8.4 and 8.9 (95% CI 2.9–28.9) when comparing the highest and lowest categories [Mirbod et al. 1992b; Kivekäs et al. 1994]. Another study that examined HAVS prevalence in power tool users found no association with duration of employment (with a participation rate of only 38%) [Musson et al. 1989]. For other investigations, exposed and unexposed groups were defined by job titles. ORs for these studies ranged from 3.2 to 40.6 (relative risk [RRs] from 3.2 to 16) [Brubaker et al. 1983; Dimberg and Oden 1991; Letz et al. 1992; McKenna et al. 1993; Mirbod et al. 1992a; Mirbod et al. 1994; Nagata et al. 1993]. Three studies demonstrated varying HAVS rates for exposed groups, but included no referents [Shinev et al. 1992; Starck et al. 1990; Virokannas and Tolonen 1995].

Two investigations produced conflicting evidence related to the effects of chain saw modifications on HAVS in forestry workers. The Brubaker et al. [1987] study, observed a 28% increase in prevalence of VWF in a cohort of tree fellers over a 5-year period and claimed that saw modifications were ineffective. Saito [1987] found no new HAVS symptom development over 6 years in a cohort of chain sawyers in reducing symptoms.

Comparing construction workers to office workers, one study demonstrated an OR of 0.5 (95% CI 0.1–11.8) for HAVS. This study met none of our four criteria [Miyashita et al. 1992].

In general, the studies in Table 5c-1 show strong evidence of a positive association between exposure to HAV and vascular symptoms of HAVS.

Temporality

The temporal relationship between HAV exposure and symptoms of HAVS is well established by studies which have determined the latency between exposure and symptom onset. Of 52 studies reviewed by NIOSH in 1989, 44 included some information about the latency period for the development of vascular HAVS symptoms following initial exposure. Latency ranged from 0.7 to 17 years, with a mean of 6.3 years. Unfortunately, because most of these studies were cross-sectional (i.e., latency was determined retrospectively) and because HAVS develop slowly, the possibility of recall bias is strong [Gemne et al. 1993]. However, longitudinal studies provide support for the temporal nature of the association. Kivekäs et al. [1994], in a 7-year follow-up of Finnish lumberjacks, found a cumulative incidence rate (IR) of 14.7%, compared to a cumulative IR of only 2.3% among referents. The cumulative IR of lumberjacks who had more than 25 years of exposure at the end of the follow-up period was 30.6%. Other studies of Finnish forestry workers also showed a marked decrease in HAVS prevalence following the introduction of improved chain saws [Pyykkö and Starak 1986; Koskimies et al. 1992].

Consistency

The literature consistently shows that workers exposed to HAV develop HAVS at a substantially higher rate than workers not exposed to vibration. Although there is considerable variation in the occurrence of HAVS among different groups using similar types of vibrating tools, the lack of consistency probably is explained by methodological differences between studies (i.e., some researchers did not account for exposure variation over time in the summary estimate of exposure) or by differences in work methods, work processes, and work organization [Gemne et al. 1993]. Important also is the difference in the intensity and duration of exposure.

Coherence of Evidence

The mechanisms by which HAV produces neurological, vascular, and musculoskeletal damage are supported by some experimental evidence [Armstrong et al. 1987b; Lundborg et al. 1990; Necking et al. 1992]. Neurological and circulatory disturbances probably occur independently and by unrelated mechanisms. Vibration may directly injure the peripheral nerves, nerve endings, and mechanoreceptors, producing symptoms of numbness, tingling, pain, and loss of sensitivity. Vibration also may have direct effects on the digital arteries. The innermost layer of cells in the blood vessel walls appears especially susceptible to mechanical injury by vibration. If these vessels are damaged, they may become less sensitive to the actions of certain vasodilators that require an intact endothelium. Experiments involving lumberjacks exposed to chain saw vibration support this hypothesis [Gemne et al. 1993]. There also is evidence that the walls of the digital blood vessels are thickened in persons with HAVS [Takeuchi et al. 1986]. During cold exposure, vessels with these changes will become abnormally narrow and may close entirely [Gemne 1982]. Symptoms of numbness and tingling which characterize HAVS may be secondary to vascular constriction of the blood vessels, resulting in ischemia in the nerve-end organs.

Other evidence concerning the coherence of information regarding the association between vibration exposure and HAVS relates to background prevalence of similar disorders in the general population. One estimate placed the prevalence of Raynaud's phenomenon at 4.6% for females and 2.5% for males in the general population [Iwata and Makimo 1987]. Only 7 of the studies examined in this review found prevalence rates less than 20% among workers exposed to HAV. In the 1989 NIOSH review, only 9 of 52 cross-sectional studies reported a prevalence rate of less than 20% among workers exposed to HAV. This provides strong evidence that individuals working in vibration-exposed occupations are at much higher risk of these disorders than those in the general population.

Exposure-Response Relationship

Exposure-response relationships involving HAV have been postulated, including: (1) a relationship between the prevalence of HAVS and vibration acceleration (and cumulative exposure time), (2) a relationship between the dose and symptom severity, and/or (3) a relationship between the dose and the latency of symptom onset.

Support for the first relationship is provided by a few longitudinal studies of workers exposed to HAV. In general, all show strong evidence that decreasing the acceleration level of a hand-held vibrating tool has a positive relationship with prevalence of HAVS. In a study of Finnish forestry workers using chain saws, Koskimies et al. [1992] found that the prevalence of HAVS symptoms declined from a peak of 40% to 5% after the introduction of light-weight, low-vibration chain saws with reduced acceleration from 14 to 2 m/s^2. Likewise, a study of similar workers in Japan found that the prevalence of vascular symptoms among chain saw operators who began their jobs before the introduction of various engineering and administrative controls peaked at 63%. (Vibration acceleration levels for chain saws used during this period ranged from 111 to 304 m/s^2.) In contrast, the peak prevalence for chain saw operators who began working after the introduction of antivibration chain saws (acceleration level: 10-33 m/s^2) and exposure duration limits (2 hrs/day) was only 2% [Futatsuka and Uneno 1985, 1986].

NIOSH authors ranked 23 cross-sectional studies that measured HAV acceleration levels and estimated a prevalence rate for vascular symptoms [NIOSH 1989]. To test whether a linear relationship existed between the HAV level and the prevalence of vascular symptoms, a correlation coefficient was calculated. The correlation analysis found a statistically significant linear relationship between HAV acceleration level and prevalence of vascular symptoms (R 0.67, $p<0.01$), indicating that prevalence of vascular symptoms tends to increase as the HAV acceleration level increases. However, the absorption of vibration energy by the hand is influenced by the vibration intensity, as well as by frequency, transmission direction, grip and feed forces, hand-arm postures, and anthropometric factors [Gemne et al. 1993].

Several studies reviewed for the current document found relationships between prevalence of HAVS and duration of vibration-exposed work [Bovenzi 1994; Bovenzi et al. 1995; Letz et al. 1992; Nilsson et al. 1989]. One cross-sectional study with a very poor response rate found no association with duration of exposure [Musson et al. 1989].

Justification for a relationship between dose and HAVS prevalence and symptom severity is provided by Bovenzi et al. [1988] and Mirbod et al. [1992b]. In a study of stone-cutters using rock drills and chisel hammers, Bovenzi found that HAVS prevalence increased linearly with the total number of working hours, from about 18% for persons with 6,000 hrs of exposure, to more than 50% among persons with more than 26,000 hrs of exposure. Likewise, in a study of 447 workers using chain saws, Mirbod et al. [1992b] found that the prevalence of HAVS increased from 2.5% among workers with less than 14 years of exposure to 11.7% among workers with 20–24 years exposure, to 20.9% among workers exposed 30 years or more. Both studies found a statistically significant correlation between the severity of symptoms (graded according to the Taylor-Pelmear scale) and a dose measure based on total exposure time.

Support for a relationship between dose and latency of symptom onset is provided by British studies conducted in the 1970s among various occupational groups, including chain sawyers, grinders, chiselers and swagers [Gemne et al. 1993]. Exposure to 10-25 m/s^2 chainsaw vibration correlated with a latency of about 3 years. Pedestal grinders using machines with zirconium wheels were exposed to vibration levels of 50 m/s^2 and demonstrated a mean latency of 1.8 years, whereas grinders who used softer wheels with accelerations of 10-20 m/s^2 had a mean latency of 14 years. Exposure to 70 m/s^2 vibration during swaging correlated with a mean latency of about 7 months, although some swagers developed symptoms in as few as 6 weeks.

Confounding and HAVS

Age and metabolic disease are the primary potential confounders for HAVS.

It is important that epidemiologic studies examine non-occupational factors, and control for them. Most of the studies were able to address "age" by stratification in their analyses, or through use of multiple logistic regression. [Bovenzi and Betta 1994; Bovenzi et al. 1995; Brubaker et al. 1983, 1987; Kivekäs et al. 1994; Letz et al. 1992; McKenna et al. 1993; Mirbod et al. [1994]. Several authors controlled for metabolic disease [Bovenzi and Betta 1994; Bovenzi et al. 1995; Letz et al. 1992; McKenna et al. 1993]. This is important because of the effects that some disorders have on peripheral circulation which may have symptoms similar to HAVS.

Nonoccupational Raynaud's phenomena - a

rare disorder which mimics HAVS has been known to occur in individuals with metabolic disorders, peripheral neuropathy, alcohol-related illness, as well as other conditions.

In reviewing the methods and results of these studies, taking into account substantially elevated ORs and evidence of dose-response relationships, it appears that potential confounders do not account for the consistent relationships seen.

Review of the 20 studies, leads us to the conclusion that there is substantial evidence that as intensity and duration of exposure to vibrating tools increase, the risk of developing HAVS increases. Most of the studies showed a positive association between high level exposure to HAV and vascular symptoms of HAVS. For many of the studies there is a strong association between HAVS and exposure to vibrating tools in the workplace. The temporal relationships and consistency between exposure and symptoms of HAVS are well established in these studies. The mechanisms by which HAV produces neurological, vascular, and musculoskeletal damage are supported by some experimental evidence. Many of the studies showed an exposure-response relationship between dose of HAV and the HAVS prevalence and symptom severity.

Table 5c-1. Epidemiologic criteria used to examine studies of hand/wrist and hand/arm MSDs associated with vibration

Study (first author and year)	Risk indicator (OR, PRR, IR or *p*-value)*,†	Participation rate $70%	Physical examination or cold provocation	Investigator blinded to case and/or exposure status	Basis for assessing hand/wrist or hand/arm exposure to vibration
Met all four criteria:					
Bovenzi 1995	6.2–32.3†	Yes	Yes	Yes	Observation or measurements
Met at least one criterion:					
Bovenzi 1988	6.06†	NR‡	Yes	NR	Observation or measurements
Bovenzi 1994	9.33†	Yes	Yes	No	Observation or measurements
Brubaker 1983	NR	Yes	Yes	NR	Job titles or self-reports
Brubaker 1987	NR	No	Yes	NR	Observation or measurements
Dimberg 1991	NR†	Yes	No	NR	Job titles or self-reports
Kivekäs 1994	3.4–6.5†	Yes	Yes	Yes	Job titles or self-reports
Koskimies 1992	NR	Yes	Yes	NR	Observation or measurements
Letz 1992	5.0–40.6†	Yes	No	No	Job titles or self-reports—previous study results used
McKenna 1993	24.0†	NR	Yes	No	Job titles or self-reports
Mirbod 1992a, 1994	3.77†	NR	No	NR	Observation or measurements
Mirbod 1992b	NR	NR	Yes	No	Observation or measurements
Musson 1989	NR	No	No	NR	Observation or measurements
Nagata 1993	7.1†	NR	Yes	No	Job titles or self-reports
Nilsson 1989	14–85†	Yes	Yes	NR	Observation or measurements
Saito 1987	NR	No	Yes	NR	Job titles or self-reports
Shinev 1992	NR	NR	Yes	NR	Observation or measurements
Starck 1990	NR	NR	No	No	Observation or measurements
Virokannas 1995	NR†	NR	Yes	NR	Observation or measurements
Met none of the criteria:					
Miyashita 1992	0.5	NR	No	No	Job titles or self-reports

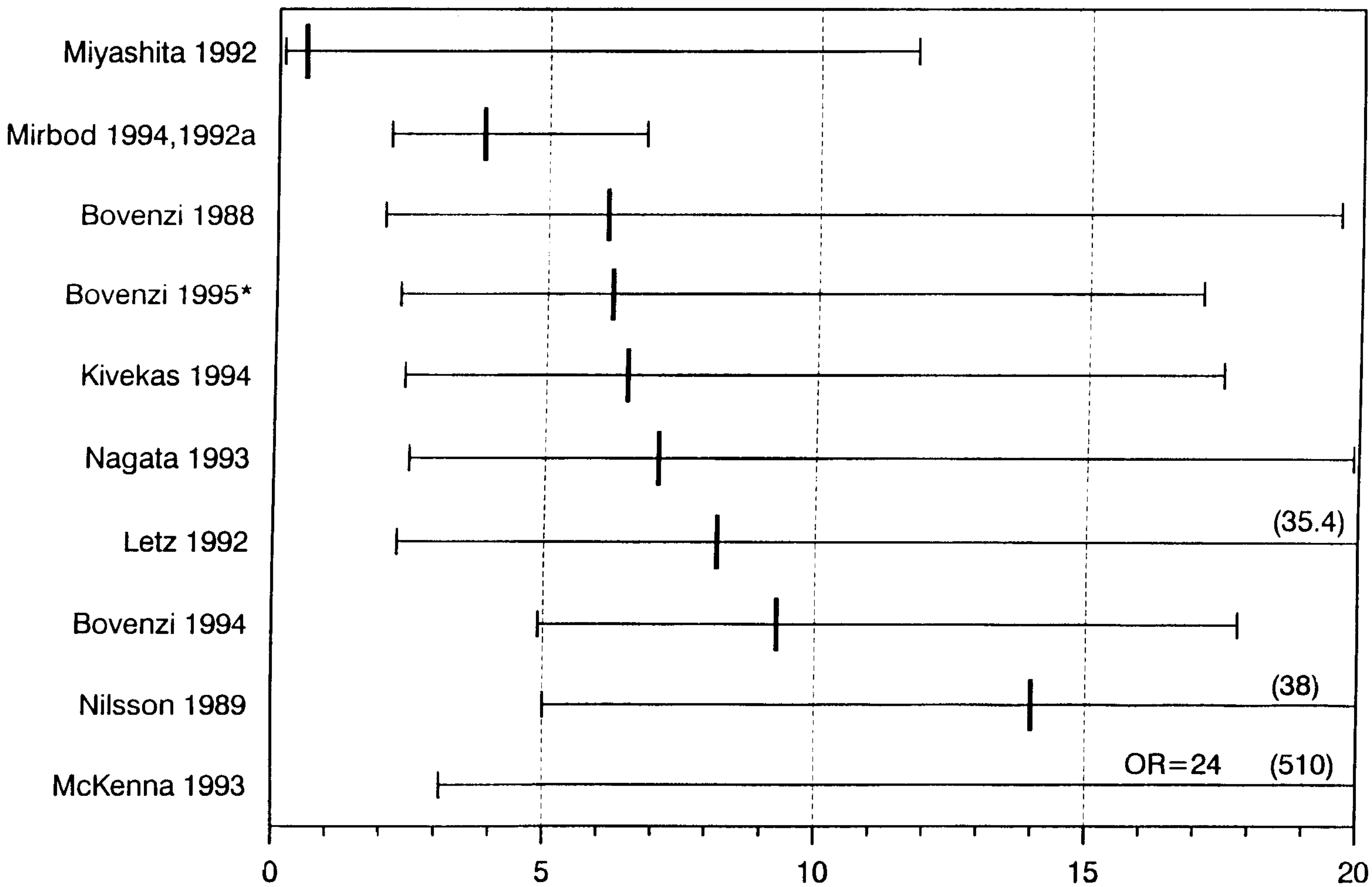
*Some risk indicators are based on a combination of risk factors–not on vibration alone (i.e., vibration plus force, posture, or repetition). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

†Indicates statistical significance. If combined with NR, a significant association was reported without a numerical value.

‡Not reported.

Figure 5c-1. **Risk Indicator for Hand/Arm Vibration Syndrome**

(Odds Ratios and Confidence Intervals)



* Studies which met all four criteria.

Note: Eleven studies indicated statistically significant associations without reporting odds ratios. See Table 5c-1.

Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Bovenzi et al. 1988	Cross-sectional	Vibration-exposed stone drillers (n=32) and stone cutters/chippers (n=44); quarry and mill workers not exposed to vibration (control group, n=60).	Outcome: Assessed by physical examination and questionnaire. VWF symptoms staged using the Taylor-Pelmear scale. Exposure: Vibration exposure assessed by measuring the acceleration intensity on a sample of tools, together with subjective ratings of exposure time.	35.5%	8.3%	6.06	2.01-19.6	Participation rate: Participation rate cannot be determined from data in the study. Significant association between vibration acceleration level and severity of VWF symptoms. Mean latency period to symptom onset =12.3 yr. Frequency-weighted acceleration levels ranged from 19.7 to 36.4 m/s^2 (rock drills and chipping hammers) and from 2.4 to 4.1 m/s^2 (grinders and hand cutters).

(Continued)

Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Bovenzi and the Italian Group 1994	Cross-sectional	Case group: Stone workers employed in nine districts in Northern and Central Italy: 145 quarry drillers and 425 stone carvers exposed to vibration. Referent group: polishers and machine operators (n=258) who performed manual activity only not exposed to hand-transmitted vibration.	Outcome: HAVs assessed by physician-administered interview; sensineural symptoms staged according to Brammer [1992]. Graded according to the Stockholm scale [Gemne 1987]. Exposure: To vibrating tools assessed by interview. Vibration measured in a sample of tools used.	30.2%	4.3%	9.33	4.9-17.8	Participation rate: 100% "All the active stone workers participated in the study, so self-selection was not a source of bias." Physician administered the questionnaires containing work history and examinations, so unlikely to be blinded to case status. Adjusted for age, smoking, alcohol consumption, and upper limb injuries. Leisure activities, systemic diseases included in questionnaire. Univariate analysis showed no association between systemic diseases and vibration so was not criteria for exclusion. Univariate analysis showed no association between systemic diseases and vibration so was not criteria for exclusion. Dose–response for CTS and lifetime vibration exposure not significant. Frequency-weighted acceleration levels = 15 m/s^2 (stone drills), 21.8 m/s^2 (stone hammers), 2.84 m/s^2 (rotary grinding tools). Percent of workers affected with HAVs increased in proportion to the square root of the exposure duration.

(Continued)

Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Bovenzi et al. 1995	Cross-sectional	222 active forestry workers and 10 retired forestry workers with >400 hr of sawing compared with 195 randomly chosen shipyard workers never exposed to hand vibration. Controls excluded for cardiovascular and metabolic disease.	Outcome: (1) History of episodes of cold provoked well–demarcated blanching in one or more fingers and (2) occurrence after employment and exposure to hand vibration and vibration white finger (VWF) attacks in last 2 years and (3) abnormal digital arterial response to cold provocation. Clinically, VWF graded using Stockholm scale. Exposure: Vibration measured on front and rear of 27 antivibration (AV) chain saws used in the forest; for previous exposure assessment, 3 non-AV chain saws were measured. Vibration measurements were made in the field during cross-cutting operations by skilled workers according to ISO 7505. Forestry workers gave detailed list of chain saws used. Workplace questionnaires validated by direct interviews with employers and employees, employment records, and amount of fuel used by chain saws Daily exposure to saw vibration assessed in terms of 8-hr energy–equivalent frequency–weighted acceleration.	All Forestry workers: 23.4% Workers using only AV chain saws: 13.4% Workers using chain saws without vibration isolation systems: 51.7%	Shipyard workers: 2.6%	(adjusted OR's) 11.8 6.2 32.3 VWF operators of non-AV and AV saws vs. Operators of antivibration saws only: OR=4.0 Lifetime vibration dose in 9m (m^2S^{-4} hd) <19: OR=4.1 19-20: OR=4.7 20-21: OR=9.4 >21: OR=34.3	4.5-31.1 2.3-17.1 11.2-93 1.1-16.4 1.3-16.1 3.1-28.4 11.9-99	Participation rate: 95% vibrating tool users, not reported for control. Analysis controlled for age, smoking, drinking habits. Physicians blinded to case status–since cold provocation test was used, it was not an issue. Smoking, alcohol, metabolic, cardiovascular, neurologic, previous musculoskeletal injuries, use of medicines included in questionnaire and accounted for in logistic regression model. Cold provocation testing performed on both forestry workers and controls. Exposure–response relationship found between VWF and vibration exposure: the expected prevalence of VWF increased almost linearly to either the 8-hr energy–equivalent frequency–weighted acceleration or the number of years of exposure (with equivalent acceleration unchanged).

(Continued)

Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Brubaker et al. 1983	Cross-sectional	146 tree fellers in 7 camps employed for $1 year compared to 142 workers not exposed to vibration matched for location.	Outcome: VWF symptoms staged using Taylor-Pelmear scale. Ischemic water bath testing for VWF completed on all subjects. Exposure was based on questionnaire data.	With symptoms: 51% Stage 3: 22% Excluding other vibration exposure and medical history: 54% Stage 3: 25%	With symptoms: 5% Stage 3: 2% 2% Stage 3: 1%	ð	ð	Participation rate: 100%. Smoking, no significant differences. Age was significantly different between cases and controls. Height and weight not significantly different. Mean latency period between work and symptoms 8.6 years. Records of duration of exposure.

(Continued)

Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Brubaker et al. 1987	Cohort: 5-year follow-up of exposed group.	Fellers at Canadian lumber camps (n=71) who had been interviewed and tested in 1979 to 1980 then again in 1984 to 1985.	Outcome: Defined as HAVs symptoms, assessed by questionnaire and digit systolic blood pressure. VWF symptoms staged using Taylor-Pelmear scale. Ischemic water bath testing for VWF completed on all subjects. Exposure: Vibration measurements recorded from a representative sample of chain saws used in the logging camp.	Raynaud's symptoms: 53% (1984 to 1985) Tingling, numbness: 56% (1984 to 1985)	Raynaud's symptoms: 51% (1979 to 1980) Tingling numbness: 65% (1979 to 1980)	õ	õ	Participation rate: 53%. Original group (1979 to 1980) included 146 fellers. 16 fellers excluded because of potential confounders. Author concluded antivibration saws not effective at preventing HAVs. 15% of fellers reported new symptoms of VWF over 5-year period. 28% increase in prevalence of VWF in workers using antivibration chain-saws. Correlation between objective test and symptoms poor: 54% reporting symptoms with positive findings on objective tests.

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Dimberg and Oden 1991	Cross-sectional	2,814 Aircraft engine workers. 68 Sheet metal workers. 26 Polishers/grinders. 20 Cleaners. 40 Forklift-truck drivers. 46 Engine testers. 146 Fitters. 49 Storemen 38 Electric welders. No control group used.	Outcome: Exposure to vibrating hand-tools assessed by questionnaire. White fingers as a spasm in blood vessels occurring in one or more fingers in connection with cooling leading to reversible pallor followed by redness. Exposure: Vibration assessed by questionnaire: working with vibrating tools, time in present job, leisure activities.	23% (polishers/ grinders) 19% (sheet metal workers) 15% (cleaners)	ð	Multivariate analysis showed increased symptoms with increasing age, work with vibrating hand tools and weight loss	ð	Participation rate: 96% questionnaire. Vibrating tool use significantly correlated with HAVs symptom prevalence. Analysis was stratified by gender, age, and employment category.

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Kivekäs et al. 1994	Cohort with 7-year follow-up (1978 to 1985)	213 lumberjacks and 140 referents.	Outcome: HAVs assessed by questionnaire, clinical examination, and radiographs. Exposure: Not measured. Exposure history determined via questionnaire.	Prevalence (HAVs) 1978: 16.9% 1985: 24.9% Cumulative incidence, HAVs (7 years): 14.7%	Prevalence (HAVs): 1978: 5.0% 1985: 5.7% Cumulative incidence HAVs (7 years): 2.3%	For 1978: OR= 3.4 For 1985: OR= 4.4 OR=6.5	1.7-6.9 2.3-8.1 2.4-17.5	Participation rate: 76% among exposed workers, 78% among control. Follow-up group included 76% of lumberjacks and 78% of referents from original group. Adjusted for age. X-ray films read by radiologists blinded to case status After adjusting for age, no difference in lumberjacks with <15-years exposure and referents, but risk increased with increasing duration of exposure. For those exposed RR=8.9 (2.9-28.9). No X-ray differences in prevalence of detectable translucencies or osteoarthritic changes in wrists or hands.

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Koskimies et al. 1992	Cohort (18-year follow-up)	Finnish forest workers (n=118-124).	Outcome: HAVs assessed by questionnaire and physical examination. Exposure: Vibration acceleration of the front handle of chain saws analyzed.	Prevalence of HAVs among forestry workers in 1990: 5%	Prevalence of HAVs among forestry workers in 1972: 40%	õ	õ	Participation rate: 100% of those who had a yearly physical exam. Decrease in prevalence attributed to reduction in weight of saws, increase in vibration frequency, and reduction in vibration acceleration (from 14 to 2 m/s^2).

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Letz et al. 1992	Cross-sectional	Shipyard workers with full-time vibration exposure (n=103); part-time vibration exposure (n=115), and no vibration exposure (n=53, comparison group).	Outcome: HAVs assessed by self-administered questionnaire; graded according to the Stockholm scale. Vibration measurements from 51 pneumatic tools made in 3 studies. Extreme variability precluded direct comparison of tools. Number of hours per week and years using tools asked.	Vascular symptoms among part-time vibration-exposed workers: 33%	Vascular symptoms: 5.7%	Part-time vibration-exposed workers vs. controls: OR=8.23	2.3-35.4	Participation rate: 79%. Participants randomly selected within departments. Significant exposure–response relationship found after adjustment for smoking, not age or race. Average latency to symptom onset <5 years. Alcohol consumption, past medical conditions considered in analysis. Exposure–response relationship found regarding self-reported cumulative exposure to vibratory tools, sensorineural stages, and corresponding vascular classifications but no further increases in workers with > 17,000 hr of exposure. Median latency for appearance of symptoms of white finger was 8,400 hr of vibratory tool/use and 8,200 hr for numbness. Participants not blinded to purpose of questionnaire may have been over-reporting.
				Vascular symptoms among full-time vibration-exposed workers: 70.9%;		Full-time vibration-exposed workers vs. controls: OR=40.6	11-177	
				Sensorineural symptoms among part-time vibration-exposed workers: 50.4%	Sensori-neural symptoms: 17%	Part-time vibration-exposed workers vs. controls: OR= 5.0	2.1-12.1	
				Sensorineural symptoms among full-time vibration-exposed workers: 83.5%		Full-time vibration-exposed workers vs. controls: OR=24.7	9.5-67	

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
McKenna et al. 1993	Cross-sectional	46 pairs of riveters and matched control subjects (machine operators who had never used vibrating tools).	Outcome: Defined as cold-induced digital vasospasm. Exposure: To specific tools assessed via questionnaire.	35%	2%	24	3.1-510	Participation rate: Not reported. Matched on age and smoking habits. Only males studied. Excluded those with injury to neck, trunk, upper limbs. 44% of riveters had <2.5 years of vibration exposure. Did not of blind examiners because they tested the most symptomatic finger. No differences in resting finger systolic pressure, vibration perception, or finger temperature between cases and controls. 17% of riveters reported symptoms of VWF.

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Mirbod et al. 1992b	Cross-sectional	Forestry workers (n=447) No control group used.	Outcome: HAVs assessed by interview and physical examination. Symptoms graded using the Stockholm scale. Frequency-weighted vibration-acceleration measurements made on the hands of chain saw operators during different job processes.	9.6% overall 20.9% among workers with 30 or more years experience 2.5% among workers <14 years 11.7% 20 to 24 years	õ	õ	õ	Participation rate: Not reported. HAVs symptom severity positively correlated with exposure duration. Chain saw vibration levels ranged from 2.7 to 5.1 m/s^2. Low prevalence attributed to recent improvements in working conditions.

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

				MSD prevalence				
Study	Study design	Study population	Outcome and exposure	Exposed workers	Referent group	RR, OR, or PRR	95% CI	Comments
Mirbod et al. 1994; Mirbod et al. 1992a	Cross-sectional	(A) 164 male dental technicians, (B) 54 male orthopedists, (C) 256 male aircraft technicians, (D) 79 male laborers, (E) 27 male grinders, (F) 46 female sewing-machine operators, (G) 23 male tea-harvesting-machine operators, (H) 272 male chain-saw operators; compared with 1,027 males and 1,301 females not exposed to vibration.	Outcome: HAVs assessed by questionnaire, interviews, field visits, or annual health examinations. Exposure: To vibrating tools assessed by questionnaire and interviews. Hand-transmitted vibration measured among a sample of workers using representative tools in actual work activities.	(See first column for job categories) A: 4.8% B: 3.7% C: 2.3% D: 2.5% E: 3.7% F: 4.3% G: 0.0% H: 9.6%	Males: 2.7% Females: 3.4%	H vs. unexposed Males: 3.77	2.1-6.8	Participation restricted to workers age 30 to 59 years. Subjects stratified by age in analysis. Hand-transmitted vibration levels in groups A to G ranged from 1.1 to 2.5 m/s^2. Hand-transmitted vibration levels in group H ranged from 2.7 to 5.1 m/s^2.

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Miyashita et al. 1992	Cross-sectional	355 Male construction workers (machine operators) compared with 44 male office workers. (A) 184 power shovel operators. (B) 127 bulldozer operators. (C) 44 forklift operators.	Outcome: HAVs assessed by self-administered questionnaire. Exposure: Status assumed from job title (no objective measurements performed).	1.1%	2.3%	0.5	0.1-11.8	Participation rate: Not reported. Participation restricted to male workers age 30 to 49. Vibration due to construction-machinery operation.

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Musson et al. 1989	Cross-sectional	Impact power-tool users in The Netherlands (n=169). No control group used.	Outcome: HAVs based on symptoms, assessed via postal questionnaire. Exposure: Vibration intensity measured using five representative tools. Duration of vibration exposure assessed via questionnaire.	17%	õ	õ	õ	Participation rate: 38% questionnaire. Adjusted for age. Exposure duration not related to HAV symptoms.

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Nagata et al. 1993	Cross-sectional	179 chain-saw workers and 205 local inhabitants who had never used vibrating tools (control group).	Outcome: HAVs assessed by dermatological tests and physical examination. Exposure: Vibration not measured directly; exposure duration expressed as years since commencement of occupation.	>20-years exposure: 16% < 20-years exposure: 2.4%	2.9%	7.1 for >20-years vibration exposure	2.5-19.9	Participation rate: Not reported. Adjusted for age. Examiners not blinded to exposure status.

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Nilsson et al.1989	Cross-sectional	Platers (n=89) and office workers (n=61) divided into 4 groups according to current and past vibration exposure.	Outcome: Assessed by physical examination and interview. VWF symptoms staged using the Taylor-Pelmear scale.	Platers with current exposure: 42%	Office workers with no exposure: 2%	85	15- 486	Participation rate: 79% among platers, not reported among control. Controlled for age.
			Exposure: Vibration exposure assessed by measuring the acceleration intensity on a sample of tools, subjective ratings, and objective measures of exposure time.	Platers with current and former exposure.	Office workers with no vibration exposure and former exposure.	14	5-38	Vibration acceleration levels =5.5 m/s^2 (grinders), 10.3 m/s^2 (hammers), 1.5 m/s^2 (die grinders). Mean latency to symptom onset = 9.8 years.
				Platers and office workers with current or former exposure.	Office workers with no vibration experience.	56	12-269	Odds ratio increased by 11% for each year of exposure. No correlation between the Taylor-Pelmear stage and years of exposure.

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Saito 1987	Cohort: 6-year follow-up prospect-ive	Chain sawers without HAV symptoms in 1978 (n=155) followed up in 1983.	Outcome: Assessed by symptoms, skin temperature, vibration threshold, nail compression, pain sense, and cold provocation. Exposure: Chain saw operating time determined by questionnaire.	0% in 1983	0% in 1978	õ	õ	Participation: Follow-up of cohort. Improvements in chain saw design, age restrictions, and a decrease in weekly operating time credited for preventing HAV. Recovery rates of skin temperature after 10-min provocation test significantly better in 1982 and 1983 compared to 1978. Vibratory sense thresholds at 5th minute after cold provocation significantly better in 1980, 1982, and 1983 compared with 1978. Age significance correlated to recovery rates from 1978 to 1983.

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

				MSD prevalence				
Study	Study design	Study population	Outcome and exposure	Exposed workers	Referent group	RR, OR, or PRR	95% CI	Comments
Shinev et al. 1992	Cross-sectional	77 male fettlers; 59 male molders; 85 male polishers. No control group used.	Outcome: HAV assessed by neurological examination. Exposure: Vibration characteristics of chipping and caulking hammers, air tampers, and polishing machines measured.	22.1% (fettlers) 6.8% (molders) 25% (polishers)	õ	õ	õ	Participation rate: Not reported. Percussive vibration had greater effect on muscle and bone pathology than constant high-frequency vibration.

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence				Comments
				Exposed workers	Referent group	RR, OR, or PRR	95% CI	
Starck et al. 1990	Cross-sectional	Forest workers (n=200), pedestal grinders (n=12), shipyard workers (n=171), stone workers (n=16), and platers (n=5). No control group used.	Outcome: HAV based on symptoms, assessed via questionnaire. Exposure: Vibration measurements taken on a sample of tools during normal operation at the workplace.	40% (forest workers using 1st generation chain saw) 16% (forest workers using 2nd generation chain saw) <7% (forest workers using 3rd generation chain saw) 100% (for pedestal grinders with zirconium wheels) 5% (shipyard workers) 75% (stone workers using pneumatic hammers) 50% (stone workers using chisel heads) 40% (platers)	õ	õ	õ	Participation rate: Not reported. No demographic data about study participants provided. Poor correlation between vibration exposure and HAV when tools were highly impulsive.

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Table 5c–2. Epidemiologic studies evaluating work-related hand-arm vibration syndrome

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Virokannas and Tolonen 1995	Cross-sectional	Railway workers (n=31) and lumberjacks (n=32) exposed to HAV. No controls used. Article evaluates the vibration perception threshold (VPT) among exposed workers and tries to determine a dose-response relationship between exposure to HAV and the VPTs.	Outcome: “History of attack” of white finger reported by subjects. VPT and electroneuro-myography used as indicators of sensory nerve damage (outcome measure). Exposure: To vibrating tools assessed by interview. (No measurements performed). Groups asked about exposure time with self-estimated annual use of vibrating tools and vehicles (hr) and number of years of exposure to vibration. Mean (SD) duration of exposure to vibration was 8,050 (3,500) among railway workers and 21,250 (10, 950) hrs among lumberjacks.	Railway workers: 45% VWF Lumberjacks: 38% VWF	õ	õ	õ	Participation rate: Not reported. Total exposure to HAV had significant correlation with VPT in railway workers (r=0.55-0.47; *p*=0.017) and lumberjacks (r=0.77-0.59; *p*=0.003). Increase in VPT approximately 2 times greater in railway workers. 7 workers excluded—2 railway workers with polyneuropathy; 4 railway workers with CTS; 1 lumberjack with CTS. These may have been related to vibration exposure. Lumberjacks used chain saws daily >1,000 hr per year. Railway workers used hand-held tamping machines -500 hrs per year. Found peak value differences for hand-held tamping machines (40 to 60 Hz) and chain saws (120 to 150 Hz). Nerve-conduction measurements adjusted for skin temperature.