Cross-Sectional Study of the Relationship Between Repetitive Work and the Prevalence of Upper Limb Musculoskeletal Disorders

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Background *This study examined the relationship of repetitive work and other physical stressors to prevalence of upper limb discomfort, tendinitis, and carpal tunnel syndrome.*
Methods *Three hundred fifty-two workers from three companies participated. Job exposure levels for repetition and other physical stressors were quantified using an observational rating technique. Ergonomic exposures were rated on a 10-point scale, where 0 corresponded to no stress and 10 corresponded to maximum stress. Job selection was based on repetition (three categories: high, medium, and low) to ensure a wide range of exposures. Physical evaluations on all participating workers were performed by medical professionals and included a self-administered questionnaire, physical exam, and limited electrodiagnostic testing.*
Results *Repetitiveness of work was found to be significantly associated with prevalence of reported discomfort in the wrist, hand, or fingers (odds ratio (OR) = 1.17 per unit of repetition; OR = 2.45 for high vs. low repetition), tendinitis in the distal upper extremity (OR = 1.23 per unit of repetition; OR = 3.23 for high vs. low repetition), and symptoms consistent with carpal tunnel syndrome (OR = 1.16 per unit of repetition; OR = 2.32 for high vs. low repetition). An association was also found between repetitiveness of work and carpal tunnel syndrome, indicated by the combination of positive electrodiagnostic results and symptoms consistent with carpal tunnel syndrome (OR = 1.22 per unit of repetition; OR = 3.11 for high vs. low repetition).*
Conclusions *These findings indicate that repetitive work is related to upper limb discomfort, tendinitis, and carpal tunnel syndrome in workers. Further research with a wider range of exposures is needed to evaluate the effects of other physical stresses alone and in combination.* Am. J. Ind. Med. 36:248–259, 1999. *© 1999 Wiley-Liss, Inc.*

KEY WORDS: repetition; cumulative trauma disorders; ergonomics; carpal tunnel syndrome; tendinitis; discomfort

INTRODUCTION

Several physical stressors encountered in industrial work, including repeated, sustained, and forceful exertions, localized mechanical stress, awkward postures, highly dynamic movements, insufficient recovery time, exposures to low temperatures, vibration, and impulse loads have been linked to increased risk of work-related musculoskeletal disorders (WRMSDs). These disorders are also referred to as "cumulative trauma disorders," "repetitive motion

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injuries," or "repetitive stress injuries" [Armstrong et al., 1993]. WRMSDs represent a class of related disorders with several common features. They typically develop over an extended period of time, rather than after an instantaneous exposure, and they involve the soft tissues, including muscles, tendons, and/or nerves [Armstrong et al., 1993]. Specific diagnoses in the upper limb include carpal tunnel syndrome (CTS), tendinitis, DeQuervain's disease, and epicondylitis [Putz-Anderson, 1986].

Numerous studies have shown a relationship between physical stressors and WRMSDs [e.g., Cannon et al., 1981; Silverstein et al., 1986; Armstrong et al., 1987]. It is generally agreed that a dose–response relationship exists between exposure to these stressors and the prevalence or incidence rates of WRMSDs [Armstrong et al., 1993]. Most of these epidemiological studies, however, have only examined exposures in a binary classification, either present/absent or low/high. Thus, there is evidence to support the endpoints of this curve for the various stressors, but there is relatively little information concerning the increased risk associated with intermediate exposure levels. Part of the reason for this lack of information is the difficulty in quantifying exposure to the various stressors.

Repetition has been the most widely studied stressor, yet no universal definition or quantification technique exists [Latko et al., 1997]. In previous epidemiological work, classification of repetition has taken several forms, including quantitative and qualitative assessments. Some investigators characterized repetition using quantitative, production-dependent factors such as cycle time [Silverstein et al., 1986] or number of pieces handled [Kuorinka and Koskinen, 1979]. Others relied on subjective assessments, such as observation of repetitive activity [e.g., Luopajarvi et al., 1979; Punnett et al., 1985; Wieslander et al., 1989].

The results presented in this article are from a study that was designed with the primary goal of providing more information on the shape of the dose–response curve for repetition. Other stressors (e.g., force, localized mechanical stress, posture, etc.) were also considered.

SUBJECTS AND METHODS

A masked, cross-sectional epidemiological study was conducted to determine the relationship between exposure to physical stressors and prevalence of WRMSDs in industrial workers. Repetition was the stressor of primary interest, although other stressors were treated as covariates. Study participants included 352 workers at three manufacturing facilities. Exposure to physical stressors was quantified for each job by a team of experienced ergonomic analysts. Participating workers in each selected job underwent a medical evaluation conducted by a team of health professionals.

Job Selection

The selection of jobs for inclusion in this study consisted of two subtasks: 1) preliminary job selection/classification, and 2) formal analysis and final job classification. In the preliminary job selection and classification stage, a team of two or more researchers conducted a plant walk-through, during which available jobs were observed. The goal of this job selection was to obtain examples of jobs encompassing three distinct levels of repetition: low, medium, and high. Jobs were selected based on an initial subjective assessment of repetition/hand activity, based on inspection and supervisor interviews. Representative workers, equipment, and job cycles were identified, and the selected jobs were videotaped and documented. Written documentation included production standards, job tasks, workstation layout and nominal dimensions, and materials, tools, and equipment. The job information was then taken back to the university laboratory for further analysis.

In order for a site to be eligible for the study, it was necessary that the three levels of repetition were present at the plant, with at least 30 eligible workers per repetition level. Workers were eligible if they had been in their current job for at least 6 months prior to the study date. It was not possible in all cases to find single job classifications with the necessary number of workers; jobs with similar repetition rates were sometimes combined to achieve the requisite number of workers. In addition, plant management had to agree to allow the medical evaluations to occur on company time, during normal work hours.

Job Analysis

Quantification of the exposure levels for repetition and the other physical stressors was performed using an observational rating method developed for this study [Latko et al., 1997; Latko, 1997a,b]. The rating method utilizes a series of 10 cm visual-analog scales which range from 0, corresponding to no stress, to 10, corresponding to the most possible stress. A series of verbal anchors adapted for each physical risk factor, written decision criteria, and videotaped benchmark examples form the foundation of the system. These decision criteria and benchmark examples draw from a diverse group of jobs, providing a comprehensive set of guidelines that can be generalized to a wide variety of manufacturing jobs. These guidelines are intended to provide benchmarks against which the raters can compare the job being observed, promoting consistency in ratings between analysts and jobs.

In this method, repetition is defined in terms of hand activity, or how busy the hands are during the work cycle. Ratings of repetition take into account two factors: 1) amount of recovery time within the cycle, and 2) how fast the hands are moving (Fig. 1).

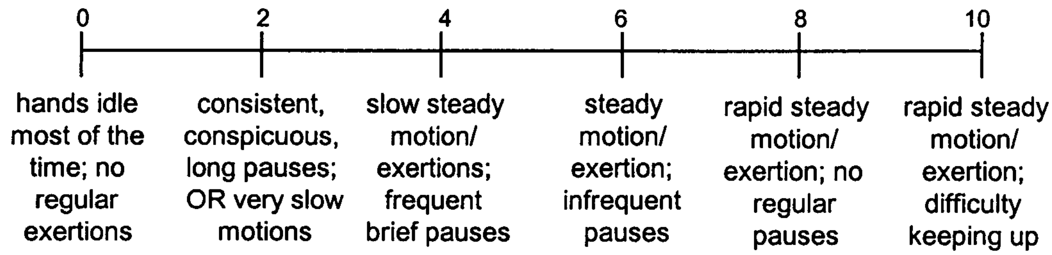

FIGURE 1. Visual-analog scale for rating repetition/hand activity, with verbal anchors, used to rate jobs of 352 manufacturing workers in the Midwest.

A total of 52 physical stressor variables were quantified for each of the jobs (Table I). The formal ratings were performed using a modified nominal group technique [Gustafson et al., 1973]. The rating team consisted of four university faculty and research staff members who were experienced in ergonomic analysis in general and this technique in particular. The videotaped jobs and documentation were presented to the team members, who independently rated the jobs for each stressor using the 10-cm scale and written guidelines. Each hand was analyzed independently. When all team members had completed their individual ratings, the ratings were discussed with the goal of reaching consensus. Consensus was defined as: 1) a difference of no more than 1 unit on the 10-cm scale between the lowest score and the highest score, and 2) the bases of all differences had been addressed. If the individual ratings for any stressor initially met consensus, no further discussion was necessary for that stressor. If consensus was not initially met, the outlying raters were given the opportunity to briefly explain the rationale for their ratings. In some cases, the discrepancies were due to observational differences: one rater simply noticed something that no one else did, or an individual overlooked something that everyone else saw. In these cases, the affected rater(s) adjusted their ratings accordingly and consensus was achieved.

TABLE I. Physical Stress Parameters Included in a Complete Rating System of Jobs of 352 Manufacturing Workers in the Midwest (Latko, 1997b)

Stressor	Aspects rated
Repetition	Overall level of hand activity
Forceful exertions	Peak and average hand force
Localized mechanical	Peak and average mechanical stress on:
Stress	Fingers
	Wrist/palm
	Forearm
	Elbow
Posture	Peak and average posture, peak and average angular velocity, and % exertion time for:
	Fingers
	Wrist
	Forearm
	Elbow
	Shoulder
	Neck
	Back
Low temperature	Peak and average hand exposure to low temperature
Vibration	Peak and average hand-arm vibration exposure
Jerk/impulse	Peak and average jerk/impulse loading of the hand

After the group agreed on the ratings for each job, the jobs from each site were again examined with regard to the inclusion criteria (i.e., availability of adequate numbers of workers in all three repetition categories). For the purposes of stratification in this study, three ranges of repetition were defined: low, medium, and high. These categories were defined by a strict division of the scale into thirds: $0-3.3 = $ low, $3.3-6.6 = $ medium, and above $6.6 = $ high. The average of the four raters was used for all analyses. Three manufacturing facilities were ultimately included in the study; they represented office furniture, spark plug, and industrial container manufacturing.

The jobs included in this study had similar exposure levels for stressors other than repetition. Because the jobs were stratified and selected solely based on repetition level, the similarity in exposure to these other stressors is not surprising. In general, ratings for the covariate stressors differed less than one unit on the scale. The exceptions were those stressors which are, by definition, related to repetition, such as average wrist velocity and wrist exertion time. These stressors had ranges of between 3–6 units. Because repetition was defined in this study as a combination of movement speed and exertion time (Fig. 1), these parameters are not independent of the repetition ratings. Previous work has shown that repetition rating can be closely modeled as a linear function of average wrist velocity and finger exertion time [Latko, 1997b].

Medical Survey

After the jobs were selected based on the above criteria, subjects were recruited for the medical survey from among the active workers performing those jobs. The only constraint on worker participation was that they had to have been performing the job of interest for at least the 6 consecutive months prior to the study date. All participants provided written informed consent and all medical evaluations were performed on company time, during normal work hours.

The medical survey consisted of four types of evaluations: a questionnaire, limited physical examination of the upper extremities, limited electrodiagnostic testing at both wrists, and general anthropometric measurements. All clinical procedures were performed by appropriately trained health professionals. Medical and job-related data collected by other members of the study team were masked from the examining clinicians.

The self-administered questionnaire focused on a variety of types of information, and has been described previously by Franzblau et al. [1993]. Demographic information, including age, race, gender, educational level, history of tobacco use, work history, job tenure, and job title was obtained. A medical history section requested information concerning the presence of diseases or conditions potentially related to WRMSDs, including diabetes mellitus, thyroid disease, rheumatoid arthritis, gynecological factors, previous surgeries, and previous acute injuries. Information was also obtained on current health status and symptoms potentially related to WRMSDs, including burning, stiffness, pain, cramping, tightness, aching, soreness, tingling, and numbness in each of 15 body locations. Subjects were instructed to report a symptom if it had been present in at least three separate episodes, or if one episode had lasted more than 1 week during the previous 12 months. This portion of the questionnaire did not ask subjects to distinguish the exact location of the symptoms, e.g., symptoms in the distribution of the median nerve from symptoms elsewhere in the fingers, hands, or wrists. If symptoms in the wrist, hand, or fingers were reported, subjects were asked to indicate if they had experienced nocturnal occurrence of the symptoms. The test-retest reliability of all aspects of the questionnaire (excluding psychosocial questions) has been shown to be good to excellent [Franzblau et al., 1997].

Each subject also completed a hand diagram [Katz and Stirrat, 1990; Katz et al., 1990; Franzblau et al., 1994] indicating whether he/she had experienced numbness, tingling, burning, or pain (NTBP) in the fingers, hands, or wrists in at least three separate episodes, or in one episode lasting more than 1 week during the previous 12 months. If any symptoms meeting these criteria had been present, he/she was instructed to shade in the distribution of the symptoms on the hand diagram. The hand diagrams were scored independently for likelihood of underlying carpal tunnel syndrome by two physicians blinded to other test results. Differences were resolved by consensus. The rating system consisted of a 4-point scale (0 = unlikely, 1 = possible, 2 = probable, and 3 = classic) as described previously [Franzblau et al., 1994].

Subjects completed a series of psychosocial evaluations, which included selected scales from the Karasek Job Content Questionnaire [Karasek, 1985], Cohen's Perceived Stress Scale [Cohen et al., 1983], and a social network questionnaire.

Anthropometric data, including height, weight, finger circumference and length (digit 2), wrist width and depth, and triceps skinfold thickness were collected. Body mass index (BMI, weight in kg divided by height in meters squared) and wrist ratio (wrist depth divided by width) were calculated.

The screening physical examination was adapted from that described by Fine [1988] and Fine and Silverstein [1995]. The physical examination included inspection, palpation, active and passive range of motion, and specific screening tests, including Tinel's, Phalen's, and Finkelstein's tests. Two-point discrimination was performed and considered normal if a subject could correctly perceive 2 points which were 4 mm apart at the tip of the index finger. Physical exams were performed by physicians trained in occupational medicine.

Bilateral limited electrophysiologic testing of each subject was performed by a board-certified electromyographer or a certified electrodiagnostic technician working under direct supervision of a board-certified electromyographer. This testing consisted of assessing sensory response recorded from digits 2 and 5 using ring electrodes following stimulation of the median and ulnar nerves, respectively, at the wrists using surface electrodes and 14 cm antidromic stimulation distance. Sensory response amplitude, peak latency, and takeoff latency were measured for each nerve tested. Hand temperature was monitored; if hand temperature was below 32°C, the hands were warmed.

Because WRMSDs encompass a variety of specific diagnoses, several health outcome measures were modeled in this study: tendinitis of the distal upper extremity, carpal tunnel syndrome (CTS), and subject-reported nonspecific discomfort (Table II). Several accepted criteria for the clinical or laboratory diagnosis of CTS are often used [Stock, 1991, 1992]. Consequently, three different case definitions of CTS are presented in this article and several other definitions were evaluated [Franzblau et al., 1993]. Models were constructed separately for the dominant and nondominant sides; only the models for the dominant side will be presented here.

Data Analysis

Data were analyzed following the approach used by Hales et al. [1994]. There were a total of 109 exposure variables analyzed: 10 anthropometry parameters, 25 medical history parameters, 5 demographic parameters, 13

TABLE II. Case Definitions of Health Outcome Measures in 352 Manufacturing Workers in the Midwest

Outcome measure	Definition
Nonspecific discomfort	Burning, stiffness, pain, cramping, tightness, aching, soreness, tingling, or numbness in the fingers, hand, or wrist
Tendinitis	Symptoms (pain, stiffness, burning, tightness, aching, or soreness) plus physical exam findings consistent with tendinitis in the elbow, forearm, wrist, hand, or fingers (pain with resisted motion, tenderness, or positive finding on appropriate test maneuver, e.g., Finkelstein's maneuver)
CTS—symptoms alone	Symptoms consistent with CTS indicated by the hand diagram ("Classic" or "Probable")
CTS—electrophysiology alone	Median mononeuropathy ("MM5"—difference in peak latency of 0.5 ms between ulnar and median nerves)
CTS—symptoms and electrophysiology combined	Positive findings on both hand diagram and electrophysiologic testing, as defined above

psychosocial parameters, 4 tobacco use parameters, and 52 ergonomic parameters. Separate analyses were performed for each of the five health outcomes presented. For each health outcome, the following three-stage process was followed:

Stage 1) Univariate analyses were performed with each of the 109 exposure parameters as independent variables. Fisher's exact test, the Pearson chi-squared test, or logistic regression was used, depending on the nature of each exposure variable. Nonsignificant variables ($P > 0.10$) were excluded from further analyses.

Stage 2) The independent variables which were not excluded in step 1 were grouped into six general categories: anthropometry, medical history, demographic, psychosocial, tobacco, and ergonomic. Multiple variable logistic analyses were conducted for each of the six categories using these remaining variables. Variables which were not significant after this stage ($P > 0.05$) were excluded from further analyses.

Stage 3) Multivariate logistic analyses were performed using all variables which were not eliminated in Stages 1 or 2. If a subject was missing data for any variables included in the final model, that subject was excluded from the analysis. Nonsignificant variables were iteratively eliminated until the final model was achieved.

All health parameters and physical stressors were analyzed for the dominant hand only. Because individuals with diabetes are likely to develop neuropathy, and because the diabetics in the study population exhibited significantly different electrophysiological results than nondiabetics, subjects who reported diabetes on the health history questionnaire were excluded from all analyses which included electrophysiologic parameters (n = 16). All analyses were adjusted for age and gender, regardless of significance of these covariates. Ergonomic parameters were modeled as continuous effects in the range 0–10, and also as ordered categorical variables (low, medium, and high).

RESULTS

A total of 438 workers were employed in the selected jobs at the time of the study and met the inclusion criteria (i.e., 6-month job tenure). Three hundred fifty-two (80%) participated in the study. Participation rates for the individual sites were 88% (office furniture), 84% (industrial container), and 76% (spark plug). Reasons for nonparticipation included absenteeism, scheduling conflicts, and refusal to participate. Table III shows the major demographic characteristics by plant and repetition category.

There was a statistically significant difference in worker age between the three repetition categories. Workers in the medium repetition jobs were the youngest (mean = 37.9), while those in the low repetition jobs were the oldest (mean = 43.0) (Table III). The gender distribution was not equal over the three categories. The low repetition jobs were predominately male (90%), while the high repetition jobs had a slightly higher percentage of females (55%). However, gender was not significant in all of the final models, as shown below. There were no differences in BMI between the groups.

TABLE III. Age and Gender Distribution by Plant and Repetition Category of 352 Manufacturing Workers in the Midwest (OF = office furniture, IC = industrial container, SP = spark plug)

	Plant	Total	Low	Medium	High
n	Combined	352	118	62	172
	OF	85	25	24	36
	IC	68	18	25	25
	SP	199	75	13	111
Age*	Combined	41.3 ± 10.5	43.0 ± 9.9	37.9 ± 9.4	41.4 ± 10.9
Mean ± SD	OF	37.2 ± 9.0			
	IC	37.0 ± 9.4			
	SP	44.5 ± 10.3			
Gender*	Combined	206/146	98/20	30/32	78/94
M/F	OF	54/31			
	IC	50/18			
	SP	102/97			

*Statistically significant difference between levels at $P < 0.05$.

TABLE IV. Linear Trend of Symptoms, Tendinitis, and CTS in the Dominant Extremity Among 352 Manufacturing Workers in the Midwest

Symptom	Total	Low (mean = 2.4)	Medium (mean = 5.4)	High (mean = 8.0)	Prob > χ^2 overall	Prob > χ^2 linear trend
n	352	118	62	172		
Wrist, hand, finger discomfort	129 (36.7%)	26 (22.0%)	23 (37.1%)	80 (46.5%)	0.0001	<0.0001
Tendinitis	35 (9.9%)	5 (4.2%)	5 (8.1%)	25 (14.5%)	0.01	0.004
CTS						
hand diagram	47 (13.4%)	8 (6.8%)	9 (14.5%)	30 (17.4%)	0.03	0.01
MM5	81 (24.0%)	30 (26.8%)	10 (16.4%)	41 (25.0%)	0.29	0.83
hand diag. + MM5	19 (5.6%)	3 (2.7%)	3 (4.9%)	13 (7.9%)	0.17	0.06

Table IV shows the general linear trends for five health outcome measures. Subjects were stratified into three repetition categories based on the repetition rating of their jobs. A strict division of the scale into thirds was used for this analysis (low = 0–3.3, medium = 3.3–6.6, high = above 6.6). In general, the linear trend was significant for discomfort, tendinitis, and the hand diagrams, but non-significant for median mononeuropathy at the wrist using the 0.5 ms threshold (MM5) (diagnostic criterion of a difference in peak latency of 0.5 ms between the ulnar and median nerve). The linear trend for CTS (defined by symptoms reported on a hand diagram and MM5) was borderline.

Nonspecific Discomfort

Thirty-seven percent of the workers reported symptoms of burning, stiffness, pain, cramping, tightness, aching, soreness, tingling, or numbness in the dominant fingers, hand, or wrist (Table IV). The prevalence of self-reported symptoms increased from 22% for workers in the low repetition jobs to 46.5% for workers in the high repetition jobs. The χ^2 test for linear trend was significant ($P < 0.0001$) (Table IV). The final stage logistic regression model using the presence/absence of these symptoms as the outcome measure is shown in Table V. Gender, history of physician-diagnosed CTS, or tendinitis and repetition level were significant terms in the final model.

Tendinitis

Ten percent of the total subject population had symptoms and physical exam findings consistent with tendinitis in the dominant elbow, forearm, wrist, hand, or fingers (Table IV). No subjects, however, exhibited the classical signs of tendinitis, i.e., swelling and redness. Prevalence rates increased from 4.2% for workers in low repetition jobs to 14.5% for workers in the high repetition jobs. There was a significant linear trend for the three levels of repetition ($P < 0.01$) (Table IV). History of soft tissue disease (i.e., tendinitis, epicondylitis, or rotator cuff syndrome) and repetition rating were significant in the final regression model (Table VI) at $P < 0.05$. Three subjects were excluded from this analysis due to missing data.

Carpal Tunnel Syndrome

Hand diagram score only (symptoms consistent with CTS).

Based on the hand diagram scores, 13.4% of the subjects exhibited ‘‘classic’’ or ‘‘probable’’ CTS in the dominant hand. There was a significant linear trend with respect to repetition level, with prevalence increasing from 6.8% for workers in the low repetition jobs to 17.4% for workers in the high repetition jobs (Table IV). Wrist ratio (depth/width) and repetition level were significant in the

TABLE V. Predictors of Discomfort in the Dominant Wrist, Hand, or Fingers Among 351 Manufacturing Workers in the Midwest

Model term	Coefficient (SE)	Prob > |Z|	Odds ratio (OR)	95% Confidence interval (CI)
Intercept	−1.86 (0.59)	0.002		
History of CTS (Y = 1, N = 0)	0.75 (0.38)	0.05	2.11	1.00–4.47
History of tendinitis (Y = 1, N = 0)	0.68 (0.31)	0.03	1.98	1.07–3.63
Gender (F = 1, M = 0)	0.72 (0.25)	0.003	2.07	1.27–3.35
Age (years)	−0.004 (0.01)	0.71	1.00	0.97–1.02
Repetition rating (0–10)	0.16 (0.05)	0.001	1.17*	1.06–1.29

*OR for 1 unit increase in repetition rating (on 10 = cm scale).
Overall log likelihood of model = −208.02.

TABLE VI. Predictors of Tendinitis in the Dominant Elbow, Forearm, Wrist, Hand, or Fingers Among 349 Manufacturing Workers in the Midwest

Model term	Coefficient (SE)	Prob > |Z|	Odds ratio (OR)	95% Confidence interval (CI)
Intercept	5.42 (1.03)	<0.001		
History of soft-tissue disease (Y = 1, N = 0)	0.96 (0.37)	0.01	2.62	1.27–5.42
Gender (F = 1, M = 0)	0.34 (0.39)	0.39	1.40	0.66–2.99
Age (years)	0.03 (0.02)	0.08	1.03	1.00–1.07
Repetition rating (0–10)	0.21 (0.09)	0.01	1.23*	1.04–1.46

*OR for 1 unit increase in repetition rating (on 10 = cm scale).
Overall log likelihood of model = 103.84.

final model (Table VII). Wrist ratio was modeled as a binary variable, with ratios at or below the 75th percentile (0.73) of the study population modeled as 0 and ratios above the 75th percentile (> 0.73) modeled as 1. Gender achieved borderline significance, both in the model and with a likelihood ratio test, with females having elevated odds, while age was not significant.

Median mononeuropathy (0.5 ms threshold).

Based on the diagnostic criterion of a difference in peak latency of 0.5 ms between the ulnar and median nerve, 24% of the subjects were classified as having median mononeuropathy in the dominant wrist. Sixteen subjects were excluded from the analyses of electrodiagnostic results due to reported diabetes. There was no significant linear trend with repetition level (Table IV); prevalence rates were similar for workers in the low and high repetition jobs (26.8% and 25%, respectively), but lower for the medium repetition jobs (16.4%). Significant terms in the logistic model were age, gender, BMI, and wrist ratio (Table VIII). No ergonomic parameters were statistically associated with this health outcome. Males were more likely than females to have median mononeuropathy, and risk also increased with age.

Hand diagram score of classic or probable (symptoms consistent with CTS) and median mononeuropathy (0.5 ms threshold) (conventional clinical definition of CTS).

When the strictest definition of CTS was used, requiring both hand diagram indications consistent with CTS and positive electrodiagnostic findings in the dominant hand, 5.6% (n = 19) of the study group met the criteria. There was an observable increasing trend in prevalence with increasing repetition; 2.7% of the workers in low repetition jobs met the diagnostic criteria, while 7.9% of the workers in the high repetition jobs met the criteria (Table IV). This trend was borderline significant at $P < 0.06$. For this health outcome, the three stage logistic regression procedure did not indicate any significant predictors at $P = 0.05$; wrist ratio and repetition rating were borderline statistically significant at $P < 0.06$ and $P < 0.08$, respectively (Table IX). Gender and age were obviously nonsignificant. A likelihood ratio test was performed for repetition rating and wrist ratio. The significance of both terms using this analysis was similar to that obtained in the logistic regression model. A more restrictive definition of CTS was also modeled (median mononeuropathy with a 0.8 ms threshold and hand diagram scores of classic or probable). In this model,

TABLE VII. Predictors of Dominant-Hand CTS Based on Hand Diagram Score of Classic or Probable Among 351 Manufacturing Workers in the Midwest

Model term	Coefficient (SE)	Prob > |Z|	Odds ratio (OR)	95% Confidence interval (CI)
Intercept	−3.52 (0.85)	<0.001		
Gender (F = 1, M = 0)	0.63 (0.34)	0.07	1.88	0.96–3.70
Age (yrs.)	0.003 (0.02)	0.85	1.00	0.97–1.03
Wrist ratio-depth/width (1 = >0.73, 0 = < 0.73)	0.95 (0.33)	0.004	2.59	1.35–4.96
Repetition rating (0–10)	0.15 (0.07)	0.05	1.16*	1.00–1.34

*OR for 1 unit increase in repetition rating (on 10 = cm scale).
Overall log likelihood of model = −127.14.

TABLE VIII. Predictors of Dominant-Hand CTS Based on Median Mononeuropathy (0.5 ms Threshold) Among 336 Manufacturing Workers in the Midwest.

Model term	Coefficient (SE)	Prob > |Z|	Odds ratio (OR)	95% Confidence interval (CI)
Intercept	−5.35 (0.88)			
Gender (F = 1, M = 0)	−0.61 (0.29)	0.04	0.54	0.31–0.97
Age (years)	0.03 (0.01)	0.05	1.03	1.00–1.06
BMI (kg/m^2)	0.10 (0.02)	<0.001	1.11	1.06–1.16
Wrist ratio—depth/width (1 = >0.73, 0 = < 0.73)	1.02 (0.29)	0.001	2.77	1.56–4.92

Overall log likelihood of model = −163.88.

TABLE IX. Predictors of Dominant-Hand CTS Based on Median Mononeuropathy (0.5 ms Threshold) Combined With Hand Diagram Scores of Classic or Probable Among 336 Manufacturing Workers in the Midwest

Model term	Coefficient (SE)	Prob > |Z|	Odds ratio (OR)	95% Confidence interval (CI)
Intercept	−5.02 (1.30)	< 0.001		
Gender (F = 1, M = 0)	−0.15 (0.50)	0.77	0.86	0.32–2.31
Age	0.02 (0.02)	0.49	1.02	0.97–1.06
Wrist ratio (1 = >0.73, 0 = < 0.73)	0.93 (0.49)	0.06	2.53	0.97–6.57
Repetition rating (0–10)	0.20 (0.11)	0.08	1.22*	0.98–1.53

*OR for 1 unit increase in repetition rating (on 10 = cm scale).
Overall log likelihood of model = −68.87.

TABLE X. Odds Ratios (OR) Based on Changes in Repetition Level for the five Dominant Hand Health Outcome Variables Presented for Manufacturing Workers in the Midwest

Outcome measure	Low-medium (△ rating = 3.0) OR (95%CI)	Low-high (△ rating = 5.6) OR (95%CI)	Med-high (△ rating = 2.6) OR (95%CI)
Nonspecific discomfort	1.62 (1.20–2.17)	2.45 (1.42–4.24)	1.52 (1.17–1.96)
Tendinitis	1.87 (1.13–3.10)	3.23 (1.27–8.26)	1.72 (1.11–2.66)
Hand diagram ("classic" or "probable")	1.57 (1.04–2.37)	2.32 (1.07–4.99)	1.48 (1.03–2.11)
MM5	NS	NS	NS
Hand diagram + MM5	1.84 (0.94–3.59)	3.11 (0.89–10.87)	1.69 (0.95–3.03)

NS = not significant.

repetition was statistically significant at $P < 0.03$ and wrist ratio was borderline significant at $P < 0.07$; no other terms achieved statistical significance.

In the above analyses, repetition rating was modeled as a continuous variable, in the range 0–10. The original job selection criteria relied on a three-category classification of repetition (low, medium, and high), based on a division of the 10 cm scale into thirds. Table X shows the ORs for changes in repetition between the mean values in the three categories low, medium, and high based on the above analyses for the five health outcomes. The range between mean ratings for the ''low'' and ''medium'' categories was 3.0 (2.4–5.4), the range between ''low'' and ''high'' category means was 5.6 (2.4–8.0), and the range between ''medium'' and ''high'' category means was 2.6 (5.4–8.0). For the three health outcome measures which were significantly related to repetition level at $P < 0.05$, the ORs were similar. A change from low to medium repetition resulted in an OR of 1.57–1.87, depending on the outcome measure, a change from low to high yielded an OR of 2.32–3.23, and changes from medium to high resulted in an OR of 1.48–1.72 (Table X).

DISCUSSION

In this study, repetition was found to be associated with worker-reported discomfort in the wrist, hand, and fingers, tendinitis of the elbow, forearms, wrist, hand, and fingers, and symptoms consistent with CTS as reported on a hand diagram. Workers in high repetition jobs (average repetition rating of 8) had 2 to 3 times higher risk of these health outcomes than did workers in low repetition jobs (average repetition rating of 2.4). Electrodiagnostic measures alone did not show any statistically significant relationship to repetitiveness of work. When the health outcome was defined as the combination of median mononeuropathy defined by nerve conduction testing and hand diagram symptoms, repetition was close to achieving significance ($P < 0.08$ and $P < 0.06$ for logistic model and linear trend, respectively). There was a relatively small number of subjects ($n = 19$) who tested positive for CTS using this case definition (Table IV), making it more difficult to show a statistical association. A clear linear trend is observable in the data, which is borderline significant. It is possible that this trend would achieve significance with a larger sample size.

A fourth site (an automotive components manufacturer) participated in this study. Management at this site did not allow workers to participate in the medical evaluation during company time, instead requiring them to participate either before or after work, without pay. This led to a participation rate of approximately 45%, well below the 80% average rate at the other three sites. Because of the possible selection bias resulting from this situation, the results of this group are not included in the above report. However, when the data from the automotive components manufacturer ($n = 67$) are included in the analysis, the resulting models are similar to those reported above.

For the health outcome parameters where a statistically significant association was found, the ORs for repetition in this study were similar to those determined in previous studies linking repetitive work to adverse health outcomes in workers. In this study, the increased odds of discomfort associated with an increase of 1 unit on the 10-cm repetition scale was approximately 1.16 (Table V). Extending this to the average ratings of jobs in the high vs. low repetition categories results in an OR of 2.45. In a study of garment industry workers, Punnett et al. [1985] found ORs of 2.7 and 3.9 for persistent pain, numbness, or tingling in the hand or wrist, respectively, for workers whose jobs required repetitive hand movements vs. those whose jobs did not require repetitive motions. In a comparison of ski manufacturing workers in "clearly highly repetitive" and "not repetitive" jobs, Barnhart et al. [1991] reported ORs of 1.22 for hand pain in the right hand, and 1.17 for any symptoms in the right hand.

Symptoms consistent with CTS as identified on the hand diagram had an OR of 1.16 per unit of repetition, or 2.32 for high vs. low repetition in the current study (see Table VII). In a study of CTS as determined by physical exam and interview among a large industrial population, Silverstein et al. [1987] found an OR of 2.7 for high repetitive-low force jobs compared to low repetitive-low force jobs. When Punnett et al. [1985] examined symptoms specifically related to CTS, the ORs for the two groups was 3.0. Cannon et al. [1981], in a case-control study of CTS patients vs. matched controls, found an OR of 2.1 related to performance of repetitive motion tasks. These three studies relied only on symptoms and/or physical exam findings consistent with CTS, and did not include any electrodiagnostic testing.

In the current study, an association was found between repetitive work and diagnosis of CTS when positive electrophysiologic findings and symptoms were included in the diagnostic criteria. Previous investigators have had differing results. Barnhart et al. [1991] found a significant relationship between repetitive work and difference in peak latency of 0.5 ms (distal sensory latency of the median nerve minus the distal sensory latency of the ulnar nerve) ($OR = 2.32$), but no significant relationship when the stricter diagnostic criteria of the 0.5 ms latency plus positive test results (Phalen's or Tinel's) or symptoms consistent with CTS were used. Wieslander et al. [1989] found a positive relationship between the performance of repetitive wrist movements at work and CTS defined by both diagnosis by a surgeon and positive electrophysiologic results for workers who had the work exposure for more than 20 years ($OR = 4.6$), but not for workers with less job tenure.

Twenty-four percent of all the workers in the current study had abnormal electrophysiologic test results (Table IV). This rate is comparable to rates determined by other investigators among working populations. In a previous study of industrial workers using methods similar to those described here, Franzblau et al. [1993] found 23.8% of subjects with median mononeuropathy in the wrist(s). Barnhart et al. [1991] reported that 31% of the workers with repetitive jobs and 19% of the workers in nonrepetitive jobs had peak sensory latency differences between the ulnar and median nerve of at least 0.5 ms. Nathan et al. [1988] reported that 39% of 471 randomly selected workers in four industries had peak sensory latency differences between the ulnar and median nerve of at least 0.4 ms, although their results may have been biased by a low participation rate.

Finally, Werner et al. [1997] compared a subset of the industrial workers who participated in this study to clerical workers. The same screening protocol and job analysis method were used to study the clerical workers. An electrophysiologic measure of median mononeuropathy was used as the health outcome in the study of clerical workers. They found that industrial workers had twice the risk of a median mononeuropathy (difference in peak latency of 0.5 ms between the ulnar and median nerve) compared to clerical workers. In addition, age and BMI were also significant independent risk factors and explained more of the variance in the model than type of work (industrial vs. clerical).

Further analyses were performed using slight variations in the definitions of both exposure and health outcome criteria in order to test the robustness of the associations found (results not shown). The analysis presented in Table VII considers a hand diagram score of ‘‘probable’’ or ‘‘classic’’ to indicate presence of CTS. Changing the analysis to also include scores of ‘‘possible’’ does not change the significant parameters. Restricting the criteria to include only scores of ‘‘classic’’ likewise yields similar results. When presence of subjects reporting ‘‘numbness, tingling, burning, or pain’’ is substituted in the model for the hand diagram score, repetition still is a significant parameter, although wrist ratio is not. In this study, median mononeuropathy was defined as a difference in peak latencies (ulnar-median) of at least 0.5 ms. While this is a commonly used threshold for diagnosis of CTS, a threshold of 0.8 ms is also sometimes used [Franzblau et al., 1994; Stetson et al., 1993]. Using this more restrictive criterion does not change the significant terms in the model containing median mononeuropathy alone as the health outcome. When these alternative definitions are combined in the strictest CTS model (presence of symptoms plus positive electrodiagnostic findings), there are minor changes in the magnitudes of the model terms. When the definition of CTS is changed to reflect a hand diagram score of 2 or 3 and median mononeuropathy (0.8 ms threshold), repetition becomes significant, while none of the other parameters change. When CTS is modeled as reported numbness, tingling, burning, or pain and median mononeuropathy (0.5 ms threshold), repetition is again significant, while wrist ratio is not. The high level of similarity between the models when alternative diagnostic parameters are substituted indicates that the findings are robust to alternative definitions of disease. The significance of repetition in these alternative models of CTS provides further evidence of an association between repetitive work and CTS, despite the borderline statistical significance reported in Table IX.

Previous studies examining the relationship between repetitive work and adverse health outcomes in workers have modeled exposure as a binary variable. The definition of repetition used in this study is unique in that it quantifies repetition on a continuous scale from 0 to 10. As indicated by Hagberg [1992], modeling more levels of an exposure tends to decrease the likelihood of significance. Modeling as two or three categories (low/high or low/medium/high) based on the repetition ratings yields similar ORs to those reported in Table X (results not shown). The repetition rating method used in this study has undergone both reliability and validity testing [Latko, 1997a,b; Latko et al., 1997], with satisfactory results for both. Similarly, the questionnaire used in this study has been shown to have good to excellent test-retest reliability [Franzblau et al., 1997].

No other physical stresses (e.g., force, posture) were found to be associated with any health outcome measure. This is not surprising, considering the range of exposures to these other stressors encountered. Because the job selection was stratified only on repetition, no effort was made to ensure wide representation of the other stressors. In general, most of the exposure levels for the other stressors fell within a 2 or 3 unit range on the 10-cm scale. It is likely that this is not enough variability in exposure to produce significant results.

Several of the studies cited above, such as Punnett et al. [1985] and Barnhart et al. [1991], defined repetition solely in qualitative terms, identifying the presence or absence of repetitive movements. This classification of repetition does not isolate exposure to repetition from exposure to other stressors. It is possible that exposure to repetitive hand activities may be confounded with exposure to other stressors, such as forceful exertions or awkward postures. In the study reported here, exposure to these other physical stressors was also quantified. Exposure levels were found to be similar between the different levels of repetition. This strengthens the conclusion that the increased risk observed is due to increased repetitiveness, and not due to another factor (such as force or posture) that coincidentally varied with repetition.

There were no consistent gender effects found in this study. Females were approximately twice as likely to report discomfort and symptoms of CTS than were males (see Tables V, VII). In contrast, females were approximately half as likely as males to exhibit median mononeuropathy (see Table VIII). None of the other three health outcome parameters addressed in this article had significant gender effects. Age was significant only for median mononeuropathy, for which a 1-year increase in age increased risk 3%.

Plant effects were modeled as dummy variables in the initial univariate analysis of each health outcome. These effects were not significant. As an additional check, plant effects were forced into the final models and again they were not significant.

There are several limitations to this study. This was a cross-sectional study, which does not allow any temporal association to be determined [Hennekens and Buring, 1987], although study participants were limited to those who had been on the job at least 6 months in an attempt to lessen the chance that disorders observed were related to previous work experience. There is also the possibility of a survivor effect, i.e., that workers who have had problems have left the workplace or changed jobs because of those problems, and that the population remaining is particularly resistant to such problems. The survivor effect would, however, tend to reduce the associations found between work and health outcomes. In addition, workers were not randomly assigned to jobs or repetition exposure in their jobs and potential bias exists there. Workers were not told how repetition exposure of their job was classified. However, they did know that they were participating in an ergonomics study that was examining the effects of workplace risk factors and the development of musculoskeletal disorders.

Worker exposure to physical stressors other than repetition was relatively low and did not vary much between jobs, making it unlikely to determine an association between these stressors and the various health outcomes. Exposure to physical stressors was evaluated for one representative worker in each job classification. Although the investigators attempted to ascertain that the worker evaluated was representative, it is possible that exposures varied between workers. It is unlikely that repetition rates would vary significantly, because most of the jobs included in this study were machine-paced, performed in a work cell (i.e., group-paced), or had strict production standards. Stresses such as posture, however, may have had variability due to individual work style and anthropometry. Finally, the subjects in this study were limited to employees at companies which were receptive to participation in the study and agreed to allow the medical evaluations to be performed on company time. There is a possibility that the management attitude and culture at these companies may be different than at other companies. This could potentially bias the results, although it is not clear whether such bias would be positive or negative with respect to repetition.

CONCLUSION

This study clearly indicates a link between repetitive work and specific upper-limb musculoskeletal disorders in workers (i.e., nonspecific symptoms, tendinitis, and CTS defined in various ways). No clear link was found between repetitive work alone and purely electrophysiologic signs of CTS. However, the number of cases for some outcomes was modest or small, which makes it more difficult to detect significant effects. The results of this study indicate the need for future studies examining the relationship between a wide range of exposures to combinations of stressors and health effects on workers. Similar studies examining a wider variety of workplaces (e.g., offices), with more variability in exposures to other stressors, are also needed.

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