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Occupational Factors and Carpal Tunnel Syndrome

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Carpal tunnel syndrome (CTS) is the most commonly reported nerve entrapment syndrome. The prevalence of CTS among 652 active workers in jobs with specific hand force and repetitiveness characteristics was estimated. The prevalence of CTS ranged from 0.6% among workers in low force-low repetitive jobs to 5.6% among workers in high force-high repetitive jobs. When controlling for potential confounders, the odds ratio for the high force-high repetitive jobs was more than 15 ($p < .001$) compared to the low force-low repetitive jobs. High repetitiveness appears to be a greater risk factor than high force (odds ratio of 5.5, $p < .05$ versus 2.9 and not statistically significant).

Key words: repetitive trauma, Carpel tunnel syndrome, nerve entrapment

INTRODUCTION

Carpal tunnel syndrome (CTS) is the most commonly reported nerve entrapment syndrome [Phalen, 1972]. Nonoccupational factors reported to be associated with carpal tunnel syndrome include several chronic diseases (rheumatoid arthritis, gout, diabetes mellitus, hypothyroidism), congenital defects such as anomolous muscles, acute trauma to the wrist, age, female gender [Tanzer, 1959; Kendall, 1960; Phalen, 1972], birth control pill use [Sabour and Fadel, 1970], pregnancy [Massey, 1978], bilateral oophorectomy [Cannon et al, 1981], and wrist size or shape [Gelmers, 1981; Johnson et al, 1981].

Occupational factors reported to be associated with carpal tunnel syndrome include forceful and repetitive hand motions, awkward postures, mechanical stress at the base of the palm, and vibration [Rothfleisch and Sherman, 1978; Armstrong and Chaffin, 1979; Cannon et al, 1981; Armstrong, 1983; Feldman et al, 1983].

Despite increased worker and management concern and media attention [Lublin, 1983], there has been little documentation of actual incidence or prevalence of occupationally related carpal tunnel syndrome in the scientific literature. The main objective of this cross-sectional investigation was to determine if forceful and repetitive job attributes were positively associated with symptoms and physical signs of carpal tunnel syndrome (CTS).

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MATERIALS AND METHODS

Study participants included 652 active workers in 39 jobs from seven different industrial sites whose jobs were categorized into four exposure groups: 1. Low force-low repetitive (LOF.LOR) 2. High force-low repetitive (HIF.LOR) 3. Low force-high repetitive (LOF.HIR) 4. High force-high repetitive (HIF.HIR).

Job Selection

All jobs at each site with at least 20 workers were identified and reviewed on plant walk-throughs by investigators (blinded to worker health problems) who observed representative workers and estimated cycle time, production rates, and weight of parts handled. If the job had a repeated sequence of steps within the work cycle, the sequence was defined as a "fundamental cycle." *High repetitive* jobs were defined as those with a cycle time of less than 30 seconds *or* more than 50% of the cycle time involved performing the same kind of fundamental cycles. *Low repetitive* jobs were those with a cycle time of more than 30 seconds *and* for which less than 50% of the cycle time involved performing the same kind of fundamental cycles. *High force* jobs were those with estimated average hand force requirements of more than 4 kg, and *low force* jobs were those with estimated average hand force requirements below 1 kg.

Workers in low force-low repetitive jobs served as an internal comparison population for the other three groups (Table I).

Job Analysis

Jobs chosen on the basis of initial walk-through classifications were analyzed in greater detail to verify their walk-through classification. At least three representative workers in each selected job were videotaped (two cameras) performing the job for at least three cycles. Playback of the videotape in slow motion allowed a more detailed estimation of number and percent of cycle time spent in fundamental cycles to characterize repetitiveness.

Postural data were abstracted from the videotapes three times per second for at least three cycles per subject. Wrist posture was characterized in terms of flexion and extension (more than 45° flexed, 15–45° flexion, neutral, 15–45° extension, and more than 45° extension) and deviation (ulnar, neutral, radial). Hand posture was characterized in terms of six types of grip (Fig. 1) [Armstrong et al, 1982]. Percent of cycle time spent in these postures, averaged over three subjects per job, was used to summarize postural variables.

Bilateral surface electromyographic (EMG) recordings (incorporated into the video mixer system) from the forearm flexor muscles were used to estimate hand force requirements of the job. All EMGs were calibrated to known forces before and after the subject was filmed. Wrist posture and grip type were considered in the calibration [Armstrong et al, 1979]. This information was abstracted from the video system, approximately 3 frames per second. Mean force and standard deviation for the right and left hand were estimated and averaged over subjects performing the same job.

To characterize force requirements of different types of jobs, various schemes were considered to take into account extreme variability in force within the cycle. For example, for jobs with long cycle times and periodic high peak forces, the mean

TABLE I. Study Jobs Selected by Plant*

Category	Study job
Plant 1. Electronics assembly, southern USA, 6,000 employees	
LOF.LOR:	Circuit board—insert and solder wires into boards[a]
	Solder touchup—solder and repair circuit boards
HIF.LOR:	Mold housing—unload parts from injection molding machine and finish
	Automatic press—load and unload bins from large presses
LOF.HIR:	Eyeletting—feed small parts into punch machine
	Drill and tap—feed plastic parts into thread machine
HIF.HIR:	Buffing—use stationary buffing wheel to polish product
	Mold handles—load and unload injection molding machine, knock out cores[a]
Plant 2. Major appliance manufacture, midwestern USA, 1,600 employees	
LOF.LOR:	Inspector—use gauges to check parts specification
HIF.LOR:	Auto screw machine—load and unload steel rods
LOF.HIR:	Punch press—load large metal blanks into punch press[a]
HIF.HIR:	Hanger—transfer parts to and from moving overhead racks (89: lids,[a] 48: motor parts)
Plant 3. Investment casting, midwestern USA, 2,200 employees	
LOF.LOR:	Wax assembly—assemble clusters of wax impressions
	Gauging—gauge parts to check specifications
HIF.LOR:	Wax injection—remove formed wax parts from dies
	Ceramic press—load and unload ceramic inserts into press
LOF.HIR:	Mounted point—fine grind small ceramic parts
	Belt sander—use small wheel to sand metal part
HIF.HIR:	Burr bench—use small hand grinder to remove burrs[a]
	Cutoff—use stationary cutting wheel to disassemble castings
Plant 4. Apparel sewing, southeastern USA, 650 employees	
LOF.LOR:	Supervisor—supervise sewing and material handling
HIF.LOR:	Material handler—load/unload warehouse material
LOF.HIR:	Hem legs—use power sewing machine to hem pantlegs[a]
HIF.HIR:	Belt loops—use machine to attach belt loops to waist band[a]
Plant 5. Ductile iron foundry, southeastern USA, 1,500 employees	
LOF.LOR:	Control panel operator—control materials flow
HIF.LOR:	Hutchinson machine operator—shell making for castings
LOF.HIR:	Core cleaner—hand file excess sand mix from cores
HIF.HIR:	Stationary grinder—grind sprue off casting
	Hand grinder—use small hand grinders to remove sprue from casting
Plant 6. Bearing manufacture, midwestern USA, 370 employees	
LOF.LOR:	Staff—office and supervisory personnel excluding typists
HIF.LOR:	Auto screw machine—load steel rods into machine
LOF.HIR:	Plunge grind operator—load/unload small shafts in automatic grinding machine[a]
HIF.HIR:	Water pump assembly—place and space balls into bearing rings and assemble
Plant 7. Bearing manufacture, midwestern USA, 500 employees	
LOF.LOR:	Plater—monitor and maintain plating tanks
HIF.LOR:	Plater helper—place bearings in racks and move to plating machine
LOF.HIR:	Manual machine operator—insert individual bearings into machine and operate[a]
HIF.HIR:	Automatic machine operator—transfer group of bearings to conveyor for machining[a]

*LOF.LOR, low force-low repetitive; HIF.LOR, high force-low repetitive; LOF.HIR, low force-high repetitive; HIF.HIR, high force-high repetetive.
[a]Changed exposure categories after detailed job analysis.

force over the cycle would tend to be low (with large variance) and mask the high peak forces. In an attempt to reflect this variability, an "adjusted force" was used. Calculation of the adjusted force [(variance/mean force) + mean force] provided the greatest numerical difference between the low force-high repetitive jobs and the high force-low repetitive jobs. All jobs with an adjusted force (either right or left hand) greater than 6 kg were designated "high force." This cutoff was selected to minimize

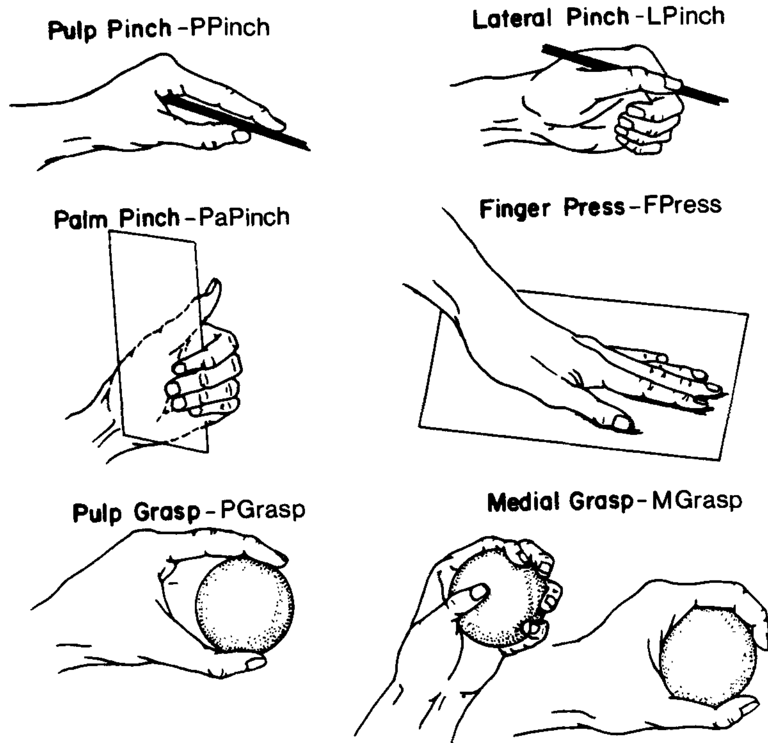

Fig. 1. Six basic classes of finger position are used: grasp, pulp pinch, lateral pinch, palm pinch, and finger pinch. Grasp is further divided into pulp grasp or medial grasp depending on how much contact there is between the hand and the object being grasped.

initial walk-through misclassification and to result in more homogeneous groups. The mean adjusted force was 3.2 ± 1.6 kg for the low force jobs and 14.5 ± 6.2 kg for the high force jobs.

Ten of 39 jobs changed exposure categories from the initial walk-through classification; four changed repetitiveness categories, and six changed force categories. No LOF.LOR jobs became HIF.HIR jobs or vice versa.

Subject Selection and Evaluation

A random sample of 12–20 active workers per job, stratified by age and gender where possible, was selected from among those with at least 1 year's seniority on the study job. Prior selection of workers (whether by employer or employee) into jobs, particularly with respect to gender, mitigated against equal distributions of males and females in many jobs.

Structured interviews and screening physical examinations (PE) were used to evaluate the health status of all subjects [Silverstein, 1985]. All health evaluations were conducted in private rooms in the plants during work hours by University of Michigan personnel (blinded to exposure status).

Interview data elicited gender, age, prior health and work history information including years on the job, prior upper extremity injuries, chronic diseases, reproductive status of females, recreational activities, and prior job activities. The remaining

questions addressed upper extremity pain or discomfort experienced in the previous 2 years. If the subject had experienced recurring difficulty in one or more parts of the upper extremity, more detailed information was sought regarding the subject's complaints including location, duration, onset, aggravating factors, and treatment.

All subjects received a standardized noninvasive PE from a research team examiner blinded to medical history and exposure. It included inspection and palpation; active, passive, and resisted range of motion testing; palpation of pulses, deep tendon reflexes, dermatome evaluation, two-point discrimination, and grip strength. Time and resource constraints precluded use of more elaborate diagnostic tools such as nerve conduction velocity studies.

Carpal tunnel syndrome was diagnosed if all the following conditions were met:

Interview

1. Symptoms of pain, numbness, or tingling in the median nerve distribution of the hand
2. Nocturnal exacerbation
3. Symptoms occurring more than 20 times or lasting more than 1 week in the previous year
4. No history of acute traumatic onset of symptoms
5. No history of rheumatoid arthritis
6. Onset of symptoms since on current job

Physical examination (PE)

1. Positive modified Phalen's test (45–60 seconds) or Tinel's sign [Phalen, 1972; Sandzen, 1981; Lister, 1984; Brown, 1977]
2. Rule out cervical root, thoracic outlet, pronator teres syndromes [Sandzen, 1981; Lister, 1984]

Statistical Analyses

In order to test the hypotheses of no association between exposure group and carpal tunnel syndrome (CTS), two basic approaches were used. Plant adjusted odds ratios (Mantel-Haenszel) were used to estimate associations between exposure and CTS, while controlling for a potential "plant effect." Unconditional multiple logistic regression techniques [Kleinbaum et al, 1982] were used to estimate associations between CTS and exposure, while controlling for potential confounders and effect modifiers (Appendix I).

RESULTS

Out of 727 eligible workers originally selected from employee rosters, 652 (89.7%) were included in the final study population (1.8% refused to participate, 3.3% were on medical leave of absence, 4.8% did not meet selection criteria, and 0.8% were excluded owing to active rheumatoid arthritis). Overall, there were no differences between males and females with respect to age or seniority (Table II). However, there were significant differences in age and years on the job by plant-gender-exposure strata ($p < .001$).

Males and females were not evenly distributed in exposure categories (Table III). Males tended to predominate in the HIF.LOR category, and females tended to predominate in the LOF.HIR category. There were both males and females in 21 out of 39 jobs surveyed.

TABLE II. Plant Combined Age and Years on the Job by Exposure Group

	Exposure group[a]			
	LOF.LOR	HIF.LOR	LOF.HIR	HIF.HIR
Age (SD)				
Males	40.6 (10.8)	39.6 (10.4)	41.3 (9.8)	37.4 (10.0)
Females	39.7 (11.2)	37.3 (8.3)	40.4 (11.4)	38.6 (9.7)
Years on job (SD)				
Males	6.4 (4.6)	8.2 (6.8)	8.3 (6.8)	9.1 (7.1)
Females	7.8 (5.8)	5.7 (3.6)	8.0 (5.6)	7.5 (5.4)

[a]LOF.LOR, low force–low repetitive; HIF.LOR, high force–low repetitive; LOF.HIR, low force–high repetitive; HIF.HIR, high force–high repetitive.

TABLE III. Gender Distribution by Plant and Exposure Group

	Exposure group[a]							
	LOF.LOR		HIF.LOR		LOF.HIR		HIF.HIR	
Plant	Male	Female	Male	Female	Male	Female	Male	Female
1	1	11	17	19	6	29	5	7
2	21	—	22	—	11	1	11	18
3	12	27	6	32	12	50	13	—
4	2	16	13	1	—	20	—	21
5	18	—	21	—	14	—	39	10
6	21	7	22	—	—	—	—	18
7	18	3	38	4	—	—	15	—
Total	93	64	139	56	43	100	83	74
Percent	26.0	21.8	38.8	19.0	12.0	34.0	23.2	25.2

[a]LOF.LOR, low force–low repetitive; HIF.LOR, high force–low repetitive; LOF.HIR, low force–high repetitive; HIF.HIR, high force–high repetitive.

There were no significant differences in reported health history or recreational activities between exposure groups, and these were not considered further.

There were 25 subjects (3.8%) who met the criteria for carpal tunnel syndrome on interview (3.1% of males and 4.8% of females) and 14 subjects (2.1%) who met the criteria on both physical exam and interview (2.0% of males and 2.4% of females).

No association was identified between reproductive history including birth control pill use, hysterectomy or bilateral oophorectomy, and symptoms of carpal tunnel syndrome among females (Table IV).

A potential gender effect was evaluated by comparing females and males in seven specific jobs on interview and five specific jobs on PE and interview with cases of carpal tunnel syndrome in which there were both females and males. The job adjusted odds ratio for females compared to males was 1.6 on interview and 0.9 on PE and interview (not statistically significant). No statistically significant trend by age group was observed. Nor was there a statistically significant difference in prevalence between plants.

Repetitiveness and Force

The 14 cases of CTS identified on PE and interview were distributed over 11 of 39 jobs. Summary estimates of force and repetitiveness for these jobs are presented in Table V.

TABLE IV. Reproductive History and Symptoms of Carpal Tunnel Syndrome (CTS) Among Females

	Bilateral oophorectomy		Hysterectomy[a]		Current BCP[b]	
	Yes	No	Yes	No	Yes	No
CTS	1	13	2	12	1	13
No CTS	27	254	58	223	33	247
Odds ratio	0.72		0.64		0.58	
95% confidence limits	0.09, 5.72		0.14, 2.91		0.07, 4.58	
Fisher exact p (two-tailed)	0.61		0.43		0.50	

[a]Females who had bilateral oophorectomies were also included in the hysterectomy analysis.
[b]Birth control pill use.

TABLE V. Force and Repetitiveness Characteristics for 11 Jobs With Carpal Tunnel Syndrome on PE and Interview

			Major fundamental cycle	
Job	Adjusted force (kg)	Cycle time (seconds)	Name (No.)	Percentage of cycle time
Buffing	9.0	22.0	Buff[a] (8–14)	87
Punch press	8.0	13.0	None	
Wax assembly	2.6	846.4	Brush[a] (86)	35
Mounted point	1.1	138.3	Sand[a] (102)	85
Burr bench	4.1	146.7	Grind[a] (340)	81
Cutoff	14.5	102.0	Cut[a] (12)	78
Hem legs	10.0	11.5	Sew[a] (2)	80
Stat grind	6.4	41.9	Grind[a] (11)	78
Hand grind(p)	9.6	12.0	Grind[a] (6)	88
Pump assembly	9.7	22.9	Inserts[a] (12)	58
Auto mach op	15.5	38.0	Load[a] (4)	44
Mean (adjusted force; cycles/hour)				
"CTS jobs"	11.8 ± 8.4		1,684 ± 1,520	
"Non-CTS jobs"	9.3 ± 7.3		999 ± 1,567	

[a]Adjusted force = (variance/mean) + mean cycle force. (Hand with highest adjusted force was used.)

CTS was not evenly distributed across exposure categories (Fig. 2). On interview, prevalence ranged from 1.3% in the LOF.LOR category to 9.6% in the HIF.HIR category. On PE and interview, the range was from 0.6% in the LOF.LOR category to 5.6% in the HIF.HIR category. Plant adjusted odds ratios indicated that the HIF.HIR group had more than 12 times the risk of having carpal tunnel syndrome on interview ($p < .01$) and more than 14 times the risk on PE and interview ($p < .05$) (Table VI).

Predictors in the logistic regression analysis (Table VII) suggested no statistically significant association between gender (female to male odds ratio = 1.2) or plant and carpal tunnel syndrome on PE and interview. Additionally, carpal tunnel syndrome was positively associated with age but negatively associated with years on the job. Exposure was the only variable in the model that achieved statistical significance ($p < .001$ on PE and interview). The HIF.HIR group had more than 15 times

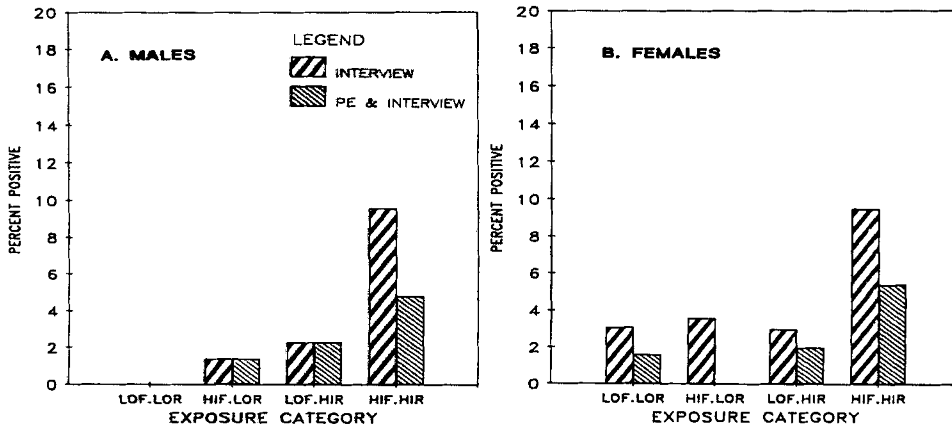

Fig. 2. Carpal tunnel syndrome by exposure group.

TABLE VI. Carpal Tunnel Syndrome by Exposure Group: Crude and Plant Adjusted Odds Ratios (OR)

	Exposure group[a]			
	LOF.LOR	HIF.LOR	LOF.HIR	HIF.HIR
Interview				
Yes	2	4	4	15
No	155	191	139	142
Percent positive	1.3	2.1	2.8	9.6
Crude OR	1.0	1.6	2.2	8.2**
Plant adjusted OR	1.0	1.0	1.3	12.4**
PE and interview				
Yes	1	2	3	8
No	156	193	140	149
Percent positive	0.6	1.0	2.1	5.6
Crude OR	1.0	1.6	3.3	8.4*
Plant adjusted OR	1.0	1.8	1.9	14.3*

[a]LOF.LOR, Low force–low repetitive; HIF.LOR, high force–low repetitive; LOF.HIR, low force–high repetitive; HIF.HIR, high force–high repetitive.
*$p < .05$: chi-square.
**$p < .01$: chi-square.

the risk on PE and interview as the LOF.LOR group. The LOF.HIR group had a slightly higher risk than the HIF.LOR group (2.7 and 1.8, respectively). There were no significant interaction terms.

Repetitiveness appeared to be a more important risk factor than force (Table VIII). The odds ratio for high repetitiveness (0,1 variable), irrespective of force, was 5.5 ($p < .05$) on PE and interview, whereas the odds ratio for high force, irrespective of repetitiveness, was 2.9 and was not statistically significant.

Other Occupational Risk Factors

Additional descriptive information was obtained by reviewing videotapes to generate hypotheses about other job factors that may have contributed to the observed associations between carpal tunnel syndrome and exposure. These include vibration and awkward postures (Table IX).

TABLE VII. Predictors of Carpal Tunnel Syndrome on PE and Interview: Multiple Logistic Regression Analysis, N = 652*

	Exposure group			
	I		II	
Model predictor	Coefficient (SE)	Odds ratio	Coefficient (SE)	Odds ratio
Gender (F:M)	.29751 (.71019)	1.3	.15996 (.70739)	1.2
Age	.02583 (.02815)	1.0	.04678 (.03104)	1.0
Years job	−.07769 (.05970)	0.9	−.10565 (.06173)	0.9
Plant 2	.31284 (1.4586)	1.4	−.56070 (1.4746)	0.6
Plant 3	1 .1547 (1. 1036)	3.2	1.4692 (1.1393)	4.3
Plant 4	.23071 (1.4241)	1.3	−.0810 (1.4638)	0.9
Plant 5	1.2937 (1.2429)	3.6	.46698 (1.2495)	1.6
Plant 6	.46651 (1.4393)	1.6	−.19189 (1.5168)	0.8
Plant 7	.93905 (1.3435)	2.6	.80110 (1.3752)	2.2
High force–low repetitive			.58937 (1.2427)	1.8
Low force–high repetitive			.99450 (1.1993)	2.7
High force–high repetitive			2.7424 (1.1276)	15.5
−2 Log likelihood	130.23		118.24	

*Statistically significant predictors: Exposure group ($p < .001$).

No quantitative measures of vibration were obtained during job evaluation. Vibration exposure ranged from a very low level on the mounted point job of delicate finishing of ceramic parts to higher levels with the stationary grinding and cutting wheels. Only one subject had a history of Raynaud's phenomenon but no symptoms consistent with carpal tunnel syndrome. Carpal tunnel syndrome was present in six of the seven jobs in which there was some vibration exposure but was not limited to those jobs. The crude odds ratio for carpal tunnel syndrome on PE and interview for those exposed to vibration was 5.3 ($p < .01$). However, jobs with vibration exposure were all high repetitive and mostly high force jobs. The crude odds ratio for HIF.HIR jobs with any vibration compared to HIF.HIR jobs without vibration was 1.9 but was not statistically significant. This suggests that there was confounding between HIF.HIR and vibration.

Commonly cited postural risk factors for carpal tunnel syndrome include ulnar deviation, wrist flexion or hyperextension, and pinching [Brain, 1947; Tanzer, 1959; Tichauer, 1966; Phalen, 1972; Smith et al, 1977; Kaplan, 1983; Armstrong, 1983].

TABLE VIII. Predictors of Carpal Tunnel Syndrome on PE and Interview: Force versus Repetitiveness (Multiple Logistic Regression Analysis, N = 652)*

Model predictor	III: Repetitiveness		IV: Force	
	Coefficient (SE)	Odds ratio	Coefficient (SE)	Odds ratio
Gender (F:M)	.00385 (.00536)	1.0	.26795 (.68581)	1.3
Age	.02577 (.02814)	1.0	.03752 (.02948)	1.0
Years job	−.08447 (.05804)	0.9	.08915 (.06132)	0.9
Exposure	1.6957 (.70795)	5.5	1.0794 (.63843)	2.9
−2 Log likelihood	123.21		127.09	

*Statistically significant predictors: High repetitiveness ($p < .05$) (plants included in all models).
−2 log likelihood without exposure = 130.23 (see Table VII).

TABLE IX. Additional Job Characteristics for Jobs With Cases of Carpal Tunnel Syndrome on PE and Interview

Job	Hand tools	Mechanical stress	Vibration	Primary postures
Buffing	None	None	Stationary buff wheel	51% ulnar, 14% flexion, 17% pinch
Punch press	Suction cup	Palm button Guards	None	27% ulnar, 29% flexion 30% pinch
Wax assembly	Brush Heat rod Eye dropper	None	None	55% ulnar, 40% flexion 98% pinch, 34% flexion with ulnar deviation
Mounted point	None	None	Small point	59% ulnar, 1% flexion 98% pinch
Burr bench	Small hand grinder	Parts[a]	Grinder	25% ulnar, 12% flexion 60% pinch
Cutoff	None	Parts[a]	Stationary cutting wheel	42% ulnar, 19% flexion 12% pinch, 14% flexion with ulnar deviation
Hem legs	None	None	None	33% ulnar, 27% flexion 77% pinch, 14% flexion with ulnar deviation
Stat grind	None	Parts[a]	Stationary grinding wheel	30% ulnar, 20% flexion 13% flexion with ulnar
Peewee hand grind	grinder	Parts[a]	Hand grinder	56% ulnar, 1% flexion
Pump assembly	Tapper	None	None	44% ulnar, 20% flexion 76% pinch
Auto mach operator	None	None	None	8% ulnar, 1% flexion

[a]Potential exists for parts to push against the base of the palm, but this was not observed on videotape.

Comparisons of cycle time spent in any of these postures or combinations of postures were made between jobs in which carpal tunnel syndrome on PE and interview had been identified and those in which it had not. "Pinch" included pulp, lateral, and palm pinches. "Awkward" included wrist flexion, hyperextension, radial or ulnar deviation. The hand with the greatest percentage of cycle time spent in the posture was used. The "carpal tunnel syndrome jobs" had slightly more ulnar deviation and pinching, but these differences were not significant (Fig. 3). Additionally, when these postural variables were entered into the logistic regression models, they were not statistically significant predictors.

DISCUSSION

Carpal tunnel syndrome was strongly associated with high force–high repetitive jobs and to a lesser extent with low force–high repetitive jobs and high force–low repetitive jobs. Repetitiveness appeared to be a stronger risk factor than force. Often cited awkward postures were not found to be strong predictors of CTS. Neither posture nor gender were major confounding variables. Vibration, however, appears to be an important confounder. These findings are qualified, taking into account limitations in study design and misclassification of exposure and health effects.

Study Design Considerations

Cross-sectional studies are most useful in identifying risk factors of a relatively frequent disease with a long duration that is often undiagnosed or unreported [Kleinbaum et al, 1982]. One limitation of the design in this study was that CTS symptoms appeared to be episodic and infrequent (3.8% on interview and 2.1% on PE and interview). Prevalence data alone cannot be used to ascertain the direction of the relationship between exposure and disease (cause and effect). Consequently, subject

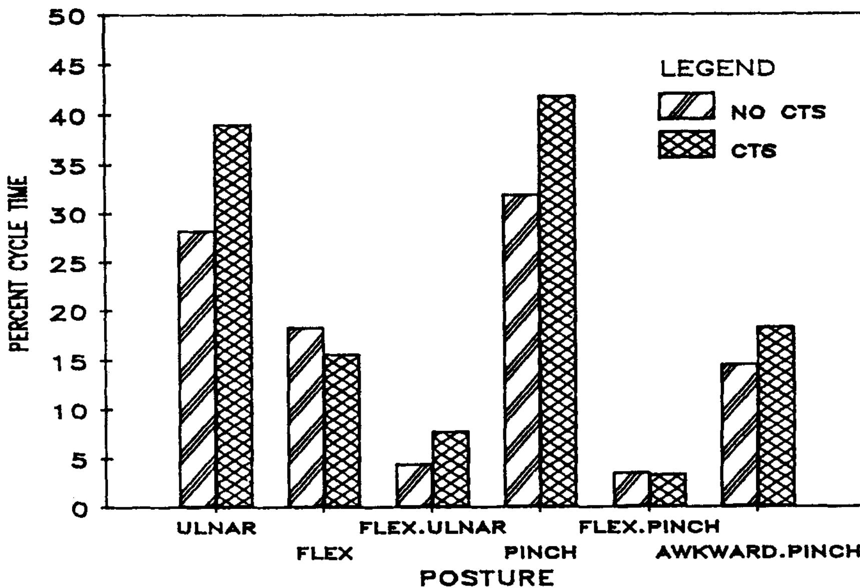

Fig. 3. Postural comparisons of jobs with and without carpal tunnel syndrome on PE and interview.

recall of date of onset was relied upon to determine if the CTS had originated while working on the study job. This retrospective component increased the probability that exposure measures reflected subject status at the time the disorder was induced [MacMahon and Pugh, 1970].

The need to study a large number of workers performing the same jobs in four different exposure categories excluded small plants from consideration. Also excluded were specific jobs (particularly assembly line jobs), which may have had a high prevalence of CTS but an insufficient number of workers. Observer bias in the selection of jobs was minimized by blinding the "selectors" to health problems identified either by management or workers on those jobs.

Survivor/Selection Bias

The study was limited to active workers with at least 1 year on the job. It was believed that workers with less seniority may have brought CTS previously obtained on another job to the one under study. Also, workers new to the job, or just returning after prolonged absence, may have experienced transient physical difficulty in adjustment. While this exclusion may have reduced the likelihood of overestimating CTS prevalence, it also could have increased the likelihood of underestimating CTS prevalence if only "survivors" were available for study. The finding that CTS was negatively associated with years on the job supports this hypothesis. Wherle [1976] noted that the mean time on the job was 2 months before onset of CTS symptoms among automotive upholstery sewers.

The extent to which workers had left the job or plant because of hand/wrist disorders, including CTS, was not known because employee rosters usually included only active workers. In one plant, seven of the 20 pump assemblers initially selected for health evaluations were off work because of carpal tunnel syndrome and or tendonitis. The effect of this exclusion was to underestimate the prevalence of CTS among pump assemblers. Studying only active workers probably underestimated the period prevalence of carpal tunnel syndrome.

Definition of Exposure

Repetitiveness was categorized as "high" and "low" on the basis of estimated cycle time and percent of cycle time performing the same fundamental cycle. Other measures of repetitiveness include number of movements or number of "awkward" movements per shift [Drury and Wick, 1984]. This is similar to total number of fundamental cycles per shift (irrespective of differences in types of postures within the different fundamental cycles). Theoretically, the overall burden on specific soft tissues would be less than if the same tissues were continually loaded. Neither of these continuous variables increased the magnitude of association, suggesting either that more elaborate modeling is necessary or that the crude categories are sufficient.

Force requirements varied tremendously. Jobs with long cycle times but intermittent high forces had relatively low mean force and large standard deviations. The "adjusted force" was used as a weighted measure in an attempt to reconcile this problem.

Misclassification of Exposure

It was not feasible to perform job analysis on all subjects who received health evaluations. At least three "representative" workers were analyzed while performing

each study job. The classification of jobs into exposure categories was based on combined summary estimates for these three workers over three cycles. Within some jobs, there was considerable variability between the three workers and their job requirements. This was more often the case with low repetitive jobs than with high repetitive jobs. The variability between individuals with similar or identical jobs was probably greatest for wrist postural variables. This is not surprising since stature often has a major impact on wrist postures assumed by individual workers during specific job activities. Individual variation within jobs for all subjects was not taken into account in the analysis. Irrespective of potential "job" misclassification, individuals performing the "same job" may have occasionally actually belonged in different exposure categories. Misclassification of exposure would most likely have led to a decreased magnitude of association with CTS.

Misclassification of Health Status

A number of blinding measures were used to minimize observer bias in the health evaluations, which included blinding examiners to interview data. Observer bias would probably have led to overestimation of associations. It is also possible that some workers may have minimized or exaggerated their symptoms on interview based on preconceptions of how their jobs were affecting their health. Exaggeration in the "exposed" groups would have resulted in overestimation of associations.

Carpal tunnel syndrome was defined on the basis of symptoms and physical findings that precipitate symptoms (Phalen's and Tinel's signs) rather than on electrodiagnositic studies. As Brown [1977] points out, "Usually the history is pathognomonic, and the physical examination is sufficiently confirmatory to make electrical studies unnecessary." A number of large clinical series reports have reported Phalen's test to be positive in 75–80% of cases and Tinel's sign to be positive in approximately 60% of cases [Phalen, 1972; Szabo et al, 1984; Swajian, 1981]. On the other hand, Posch and Marcotte [1976] found these tests to be positive in approximately 10% of nerve conduction velocity-diagnosed cases. In a study of Finnish butchers, Falck and Aarnio [1983] found abnormal nerve conduction velocities correlated with symptoms better than did clinical signs. The lack of quantification of median nerve function may introduce some degree of miclassification.

Subjects may have been misclassified as negative on physical examination (PE) becuase the PE was not sensitive enough to detect early manifestations of CTS. As Wickstrom [1982] pointed out, one of the difficulties in conducting this type of investigation is that severe cases are not to be expected in active workers. Rather, one must look for early signs, often much more subtle, of declining health in those not too incapacitated to work. Additionally, there were three subjects with evidence of CTS on PE and interview (1 male burr bench, 1 female pump assembler, 1 male automatic machine operator) who did not meet the frequency/duration of symptoms criteria. Had these subjects been included as positive, the observed associations would hvae been of a larger magnitude. The magnitude of association was similar when diagnosis was made by interview alone or by PE and interview.

Potential Confounders

There was not convincing evidence that prior health history or recreational activities were related to exposure, and these were not treated as confounders.

Contrary to most clinical and field study reports [Tanzer, 1959; Kendall, 1960; Phalen, 1972; Swajian, 1981; Mathur, 1981; Cannon et al, 1981], there was no difference in prevalence of CTS between females and males. This may be due to employee selection into different types of jobs on the basis of gender (females in high repetitive jobs and males in high force jobs). When females were compared to males performing the same job, the CTS odds ratio for females was 0.9 and was not statistically significant.

In the logistic regression analysis, age was positively associated with CTS but was not a statistically significant predictor. This supports the findings of Falck and Aarnio [1983], who investigated CTS among butchers, and Punnet [1985], who investigated CTS symptoms among garment workers. The negative association (odds ratio = 0.9, not statistically significant) between years on the study job and CTS suggest a survivor effect, identified also by Punnett [1985].

Vibration appears to be an important confounder, which was not well measured in this investigation. Some vibration exposure occurred in six of 11 jobs in which CTS was identified on PE and interview. All six of these jobs were also high repetitive and mostly high force jobs. In a case-control study of CTS in an aircraft engine plant, Cannon et al [1981] reported an odds ratio of 7 for use of vibrating hand tools and an odds ratio of 2.1 for repetitive motion. Rothfleisch and Sherman [1978] examined 16 automotive assembly workers with CTS and noted that all had used pneumatic tools, having frequencies of 8.3–33.3 Hz, at some time and that they used consistently awkward hand/wrist postures in their work. It is probable that the vibration exposure in these studies was accompanied by highly repetitive and forceful work. Localized vibration exposure stimulates muscle contraction and decreases tactility, thereby increasing the force exerted in high repetitive tasks [Radwin, 1986]. Clearly, this relationship between vibration, force, repetitiveness, and posture requires further investigation.

CONCLUSIONS

CTS was strongly associated with high force–high repetitive work and to a lesser extent with high repetitiveness alone, irrespective of other factors. High force combined with high repetitiveness appears to have more than a multiplicative effect, increasing the risk more than 5 times that of either factor alone. These findings were not explained by nonoccupational factors. While vibration and awkward postures may be important risk factors for CTS, only vibration appeared to be important in this investigation.

These findings can be helpful in directing workplace interventions in the worker-exposure-disease cycle because they suggest a strategy for primary prevention: intervention at the level of the job. Through job modification, a reduction in force and/or repetitiveness, and perhaps a change in postural factors or a reduction in vibration may result in a reduction in prevalence or incidence of occupationally related CTS.

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APPENDIX I. Occupational Factors and Carpal Tunnel Syndrome

Model:

$$P(D/X) = \frac{1}{1 + \exp^{-(Bo + BiXi)}}$$

where P(D/X) is the probability of disease given:

Variable	Description	Model
X14	Gender (0:male, 1:female)	I,II,III,IV
X15	Age	I,II,III,IV
X16	Years on specific job	I,II,III,IV
X18–22	Plant 2–7 (0, 1)	I,II,III,IV
X300	% wrist flexion	II,III,IV
X302	% pinch	II,III,IV
X303	% ulnar deviation	II,III,IV
X304	% flexion with ulnar deviation	II,III,IV
X305	% flexion with pinch	II,III,IV
X306	% hyperextension with pinch	II,III,IV
X307	% flex + extend + ulnar + radial	II,III,IV
X308	% flex + pinch	II,III,IV
X1000	Age * years on job	I,II,III,IV
X1002–1004	Age * exposure group	II
X1005	Age * gender	I,II,III,IV
X1006	Age * gender * years on job	I,II,III,IV
X1007	Gender * years on job	I,II,III,IV
X1008–1010	Gender * exposure group	II
X1011–1025	Plant * exposure group	II
X1026–1028	Years on job * exposure group	II
X1032	Gender * % pinch	II,III,IV
X2046–2048	HIF.LOR, LOF.HIR, HIF.HIR (0, 1)	II
X2051	Force (0, 1)	IV
X2052	Repetitiveness	III