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1st place, PREMUS [1] best paper competition: workplace and individual factors in wrist tendinosis among blue-collar workers – the San Francisco study

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Objective Workplace studies have linked hand/wrist tendinosis to forceful and repetitive hand exertions, but the associations are not consistent. We report findings from a prospective study of right wrist tendinosis among blue-collar workers.

Methods Workers (N=413) at four industries were followed for 28 months with questionnaires and physical examinations every 4 months to identify incident cases of right wrist tendinosis. Exposure assessment of force and repetition were based on field measurements and video analysis to determine repetition rate and the percent time (% time) in heavy pinch (>1 kg-force) or power grip (>4 kg-force). All exposure variables were measured at the level of the individual and task. For workers responsible for >1 task, a time-weighted average exposure was calculated based on task hours per week. A proportional hazards model was used to assess the relationship between exposures and incidence of wrist tendinosis.

Results During the 481 person-years of follow-up, there were 26 incident cases of right wrist tendinosis [incidence rate (IR) 5.40 cases per 100 person-years]. Adjusting for age, gender, and repetition, wrist tendinosis was associated with % time spent in heavy pinch [hazard ratio (HR) 5.01, 95% CI 1.27–19.79]. Composite exposure measure American Conference of Industrial Hygienists Threshold Limit Value (ACGIH-TLV) for hand activity level (HR 3.95, 95% CI 1.52-10.26) was also associated with the outcome for the medium-exposure group using video-based total repetition rate.

Conclusions The workplace factors predicting wrist tendinosis were time-weighted average values of % time spent in heavy pinch and the ACGIH-TLV for Hand Activity Level. The % time spent in power grip was not a significant predictor, nor were any measures of repetition. An exposure–response relationship was observed for the % time spent in heavy pinch. These findings may improve programs for preventing occupational wrist tendinosis.

Key terms exposure–response; force; MSD; musculoskeletal disorder; occupational; prospective study; repetition; upper extremity.

Historically, work-related upper-extremity musculoskeletal disorders (MSD) have comprised a significant portion of the number and cost of injuries in the workplace. Upper-extremity MSD include injuries of muscles, tendons, ligaments, and nerves in the shoulder, arm, elbow, forearm, hand and wrist. Common upper-extremity disorders include rotator cuff syndrome, medial or lateral epicondylitis, wrist tendinosis, and carpal tunnel syndrome. A distal upper-extremity injury (DUE) consists of upper-extremity MSD that are isolated to the forearm, hand, and wrist such as wrist tendinosis and carpal tunnel syndrome. The average cost of a DUE has been reported to be approximately US$6977 and up to US$8000 per case (1, 2) with a median cost of US$824, indicating that many DUE disorders are severe and costly. Upper-extremity MSD costs due to lost time at work, referred to as indemnity costs, have accounted for up to 65% of overall costs (2). The annual incidence rate for DUE has

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been reported at 2.6 per 100 workers with one third of the cases and half of lost work time due to MSD from overuse (3, 4). The overall cost of upper-extremity MSD in the United States has been estimated to be up to US$6.5 billion per year (3). Furthermore, a study by Morse et al (5) estimated that only 6–8% of work-related upper-extremity MSD are reported, indicating that the overall problem has been more severe than what claim data indicates. The problem of under-reporting upper-extremity MSD is further supported by a study showing that only 52% of employees who self-reported having a work-related injury actually filed a workers compensation claim (6). The problem of work-related upper-extremity MSD has been, and continues to be, widespread and costly.

Wrist flexor and extensor tendinopathies are common work-related DUE disorders. Tendons connect muscles to bones and repeated forceful loading may lead to inflammation, microtears, or degenerative changes in the tendon causing a tendinopathy, also commonly referred to as tendinosis. Degenerative changes of tendons are common in overuse injuries. The result is pain, stiffness, reduced range of motion, and loss of strength. Continued use of the afflicted tendon creates more pain and tissue injury, and, without proper rest or exposure reduction, can result in loss of function and disability.

Silverstein et al (1) found that high hand forces, that is, forces >44.1N (4 kg) for power grip and >8.9N (1 kg) for pinch, posed a significant risk on hand and DUE disorders, such as wrist tendinosis. Other studies have found that "high hand force" is an independent risk factor of hand and wrist tendinosis (1, 4, 7–9). Independently, repetitive motions, defined by tasks with wrist or hand exertions repeated more frequently than every 30 seconds, are associated with increased prevalence of DUE (hand and wrist) discomfort and tendinosis with an odds ratio (OR) ranging from 1.17–3.23 (1, 10, 11).

While individual physical risk factors have been shown to be associated with upper-extremity MSD, numerous studies also indicate that combinations of these same risk factors are related to even higher risk. Silverstein et al (1) found that the OR for DUE disorders in highly repetitive jobs compared to low-repetition jobs, regardless of force, was 3.3. The OR increased to 29.1 for jobs with combined exposures to high force and high repetition when compared to jobs with low force and low repetition. Knox & Moore found that the OR could be as high as 50 when exposure to high force, high repetition, and awkward posture coexisted in a job (12, 13). Several authors have proposed combining individual risk factors in formulas or indices [eg, American Conference of Industrial Hygienists Threshold Limit Value (ACGIH-TLV) for hand activity level (HAL), or the Strain Index] that may improve the prediction of upper-extremity MSD over individual physical risk factors. However, these indices have been tested in very few prospective studies for wrist tendinosis (12).

In addition, although crude relationships between repetition, force, posture and MSD are known, little is known about the exposure–response relationship between these individual risk factors and upper-extremity MSD, or their combined effect. In fact, there have not been any rigorous prospective studies to date that have assessed causal factors for wrist tendinosis. By identifying an exposure–response or threshold relationship of individual or combinations of physical risk factors for wrist tendinosis, workplace guidelines and policies for prevention can be improved.

The primary purpose of this study was to investigate whether an exposure–response relationship exists between force, repetition, or their combined effect, and wrist tendinosis. The specific aims included: reporting the incidence rate of wrist tendinosis and examining the predictive value and exposure–response relationship of various measures of force, repetition, and their summary measures.

Methods

Study participants and procedures

Participants. This was a 28-month prospective study designed to assess incidence and predictive factors for work-related upper-extremity MSD. Workers were eligible to participate if they performed primarily hand-intensive manual (not office) work and were not engaged in >4 tasks. Excluded were: employees who (i) had worked for their current employer <3 months, (ii) did not expect to be working for their current employer for ≥1 year, or (iv) spent >25% of their time on a forklift or a computer. Of 594 eligible individuals, 450 (76%) workers participated in the study, while 144 (24%) refused. Of the 450 participants, 413 had follow-up data from questionnaires and physical examinations completed every 4 months for up to 28 months.

Baseline information. A baseline interview survey assessed job parameters, previous employment history, work organizational factors, and pain in various upper-body regions including the hand/wrist region. The interview was administered in the participant's preferred language. A physical exam was triggered for the hand/wrist region when the following criteria were met: pain in the hand/wrist region occurred in the last four months and was thought by the participant to be work-related, *and* the participant reported a pain of ≥5 on a 10-point scale in the past 7 days or had taken pain medication (including over the counter medication) for the pain for ≥2 of the past 7 days.

Physical exam. Maneuvers and diagnosis criteria for 11 work-related upper-extremity disorders of the hand/wrist were modified from published criteria (14, 15). Maneuvers typically included pain over a specific tendon while contracting or stretching the muscle with the presence of one of five core signs, including: tenderness to palpation, redness, swelling, crepitance, or warmth (table 1). A licensed physical therapist completed all physical exams.

Table 1. Diagnostic criteria for right wrist tendinosis. [APL=abductor pollicis longus; EPB=extensor pollicis brevis; ECRL=extensor carpi radialis longus; ECRB=extensor carpi radialis brevis; EPL=extensor pollicis longus; EDC=extensor digitorum communis; EIP=extensor indicis pollicis; EDM=extensor digiti minimi; ECU=extensor carpi ulnaris.]

Diagnosis	Symptoms/tests outcome variables	Diagnosis Criteria
Wrist flexor tendinosis		
Flexor Carpi radialis (FCR) tendinosis	Pain scale Muscle test of FCR Core sign [a] over FCR tendon	Positive muscle test *and* ≥1 positive core sign
Flexor carpi ulnaris (FCU) Tendinosis	Pain scale Muscle test of FCU Core sign [a] over FCU tendon	Positive muscle test *and* ≥1 positive core sign
Digital flexor tendinosis (DF)	Pain scale Muscle test of DF Core sign [a] over DF tendon	Positive muscle test *and* ≥1 positive core sign
Trigger Finger	Pain scale Tenderness at A1 pulley Popping at A1 pulley Demonstrated locking	Positive tenderness *and* popping *or* locking at A1 pulley
Wrist extensor tendinosis		
Dorsal compartment 1 deQuervain's tendinosis	Pain scale Finklestein test [b] Hitchiker's sign [c] Core sign [a] over APL and EPB tendon	Positive Finklestein test *or* Hitchiker's sign
Dorsal compartment 2 Extensor carpi radialis (ECR) tendinosis	Pain scale Muscle test of ECRL and ECRB Core sign [a] over ECRL and ECRB insertion	Positive muscle test *and* ≥1 positive core sign
Intersection syndrome	Pain scale Point tenderness 2–3 cm proximal to wrist crease along ECR Localized swelling Crepitance	2 of the 3 possible signs
Dorsal compartment 3	Pain scale Muscle test of EPL Core signs [a] over EPL tendon	Positive muscle test *and* ≥1 positive core sign
Dorsal compartment 4	Pain scale Muscle test of EDC and EIP Core signs [a] over EDC and EIP tendon	Positive muscle test *and* ≥1 positive core sign
Dorsal compartment 5	Pain scale Muscle test of EDM Core signs [a] over EDM tendon	Positive muscle test *and* ≥1 positive core sign
Dorsal compartment 6	Pain scale Muscle test of ECU Core signs [a] over ECU tendon	Positive muscle test *and* ≥1 positive core sign

[a] Core signs: point tenderness, local warmth, redness, localized swelling, and crepitance
[b] Finklestein test: pain with ulnar deviation and 1st MCP flexion
[c] Hitchiker's sign: pain with resistive extension at 1st MCP

Periodic follow-up. Every 4 months, a periodic interview survey collected information on job changes such as changes in shift, overtime, tasks, stress, and other psychosocial measures. Additionally, pain levels and parasthesias in the hand/wrist region were assessed, as were functional status regarding work ability, work modifications, medication use, and healthcare. A physical exam was triggered for the hand/wrist region using the same criteria as at baseline. Physical exams were completed as close to the interview date as possible, which was an average of 25 days.

Exposure assessment. Job title and primary work tasks were assessed for all workers and confirmed during an in depth individualized field exposure assessment. Weekly hours were estimated for each task (≤4 tasks) by each participant during recruitment and confirmed during baseline data collection and during the in-depth individualized exposure assessment. Individualized field exposure assessment and video recording was completed for 295 of the 450 subjects. The exposure assessment followed the methods of Bao (16) and Bao & Silverstein (17) and has been demonstrated to provide a reliable assessment of overall exposure. The in-depth field exposure assessment data and video recordings were collected by a trained ergonomist. For workers who did not have individualized exposure assessment data (N=155), exposure levels of each task were imputed based on the median values of the participants who performed the same task. A time-weighted average of each exposure variable was calculated for each participant by weighting the exposure variable for a task by the hours worked on that task per week [eg, $X_{twa}=\Sigma$ ([task duration per week/total working time per week] × exposure value)].

The time, location, and department of exposure assessments were recorded. Shift and job details including primary tasks and the duration per week allocated to each task were collected via interview. Components of the ACGIH-TLV for HAL and the Strain Index were estimated by the ergonomist through observation. These included the HAL repetition scale, the duration of exertion, the efforts per minute, and the speed of work. Tool weight and hand force required to complete a task activity were measured directly with a force dynamometer in the posture typically used for that activity. Peak pinch and power grip forces during task activities were measured using force matching, a technique that has the worker simulate an activity with a grip or pinch dynamometer in the posture typically used for the activity. Force matching was repeated three times for each activity and averaged. The percent of maximum voluntary contraction (% MVC) in pinch or power grip was calculated by dividing the average force matching measurement per individual by his or her maximum voluntary contraction measured in the same posture (17). If the participant's MVC was not available, gender specific, maximum contraction norms closest to the posture of the activity were used. The largest % MVC value of all activities within a task was chosen to represent that task. The % MVC (0–100%) for each task was normalized to a 0–10 scale to represent the normalized peak force used in force and ACGIH-TLV for HAL analysis.

Approximately ten minutes of video were recorded for each task of each participant. The video was recorded during typical work activities. Productivity requirements, pace drivers, and the cyclic nature of each task was ascertained via interview and observation. The videos were analyzed frame-by-frame using multi-video task analysis (18). During the video analyses, the force measurements collected in the field were used to classify the hand posture for each frame as being engaged in one of five grips: (i) no load (fingers or palm in no contact with any objects); (ii) light pinch (≤1 kg force); (iii) heavy pinch(>1 kg force); (iv) light power grip (≤4 kg force), and (v) heavy power grip (>4 kg force) (17). A pinch was defined as a load that was primarily applied to the fingers. A power grip was defined as a load that was evenly distributed between the palm and the fingers or primarily located on the palm. The % time that the hand was in each grip was calculated by summing its number of frames and dividing it by the total number of frames observed for that task. The % time spent in all pinch and power grip was the sum of the % time spent in light pinch, heavy pinch, light power grip, and heavy power grip. Other summation values included the % time spent in any pinch (heavy and light pinch), any power grip (heavy and light power grip), and heavy pinch or power grip.

In addition, the repetition rate (reps/min) for hand exertions was recorded from the videos. The definition of an exertion was either a readily observed movement of the wrist or fingers, (wrist/finger extension/flexion) or a change in the load to the hand (eg, change from light to heavy). Repetition rates per task were calculated for each of the five different hand postures. Total repetitions per minute was the repetition rate across all five hand postures: no load, light pinch, heavy pinch, light power grip, and heavy power grip. Heavy pinch or power grip repetition rate was the repetition rate while in heavy pinch or heavy power grip. If the hand was not visible in a frame, the posture was allocated to a "no data" category (0.3% of all data) and the frame was not included in the calculation of repetition or % time in different grips. Both hands were evaluated separately.

Measures

Demographics, work factors, and MSD history

Standard demographic data on gender, age, ethnicity, highest grade achieved in school, salary, and number of dependents was collected. The presence of medical conditions such as diabetes, rheumatoid arthritis, lupus, gout, thyroid disease, chronic renal failure, and pregnancy was assessed. Previous physician diagnosis of MSD of the neck, low back and upper extremity was also assessed. Current and previous smoking status and medication use was recorded. The time spent engaged in different sports and upper-extremity intensive activities was assessed and ultimately summed together to provide the total number of hours per week engaged in any activity outside of work. General health was assessed on a 5-point scale [Standard Form (SF)-36]. All demographic variables described were collected via interview survey at baseline.

Information on current and previous job titles, dates of employment, supervisory roles, shift schedule, and daily work schedule, and hours of overtime was recorded.

Information on work psychosocial factors was collected at baseline using the job content questionnaire (19, 20). Job content scales including physiological demands, skill discretion, decision latitude, decision authority, coworker support, and supervisor support were generated and used to calculate job strain and iso-strain indices for each individual using median and tertile splits.

At baseline and every four months afterwards, discomfort in the hand and wrist region that lasted ≥1 week or occurred three times in the past 12 or 4 months, respectively, triggered a more thorough interview that included symptoms, pain severity, work-relatedness, treatment history, and impact on work.

Exposure variables

Hours per week on each task (≤ 4 hours) were collected during the baseline interview and confirmed at the field exposure assessment.

Force. Task-specific force measurements included those from self-report, observer-rated, direct measurement, and video motion analysis procedures (table 2). Self-report measures of force included the task-specific rate of perceived exertion and the task- and hand-specific visual analog scale (VAS) for hand fatigue at the end of the shift. The observer-rated estimate of force included the duration of exertion ranging from 0–80% of total cycle time. Direct measures of force for each hand included direct force gauge measurements of peak hand force and force matching previously described. The video analyses for each hand provided the % time spent in the five hand postures for each task as well as summation values including "any pinch", "any power grip", "heavy pinch or power grip", and "all pinch and power grips". Individual normalized peak force was calculated from the % MVC in pinch or power grip, described previously.

Table 2. Individual exposure measures by task. [MVC=maximum voluntary contraction; ACGIH-TLV for HAL=American Conference of Industrial Hygienists Threshold Limit Value for Hand Activity Level.]

	Measurement Tool	Variable Description
Exposure variables		
Force	Self-report	Borg CR-10 scale: 0–10 (categorical) Visual analog scale (continuous)
	Observer-rated	Duration of exertion (0–80%)
	Direct measurement (force matching or force measurement)	% MVC pinch: 0–100% (continuous) % MVC power grip: 0–100% (continuous) Normalized peak force (% MVC for pinch or power grip normalized to a 0–10 scale) Peak hand force Tool weight
	Video analysis	% time in: no load, light pinch, heavy pinch, light power grip, heavy power grip, any pinch, any power grip, heavy pinch or power grip, and all pinch and power grip (heavy & light) (continuous)
Repetition	Observer-rated	HAL: 0–10 scale (categorical) Speed of work: very slow, slow, fair, fast, very fast (categorical) Efforts per minute: 1–20/minute (continuous)
	Video analysis	Number of repetitions/minute: no load, light pinch, heavy pinch, light power grip, heavy power grip, any pinch, any power grip, heavy pinch or power grip, and total repetition rate (all five hand postures) (continuous)
Posture	Observer-rated	Wrist posture: very good, good, fair, bad, very bad (categorical)
Composite exposure measures		
Strain index	Force: exertion from self-rated visual analog scale and duration from video analysis while in heavy pinch or power grip Repetition and posture: observer-rated	Strain index value: >0 (continuous)
ACGIH-TLV for HAL	Direct measure of force and: Method A: observer-rated measure of repetition Method B: video analysis measure of total repetition Method C: video analysis measure of repetition in heavy pinch or power grip	Ratio: between 0–1 (continuous)

Repetition. Observer-rated repetition measurements included the HAL scale rating (0–10 scale), the speed of work rating (0–5 scale), and the efforts per minute (0–20 scale). From the video analysis, the repetition rate for all five hand grips and the summation of grips including any pinch, any power grip, heavy pinch or power grip, and total repetition were used in the analysis (table 2).

Composite exposure measures to multiple risk factors. The strain index (21) was calculated from observer-rated values of efforts per minute, speed of work, and posture, self-report identification of task duration, and intensity of effort using the VAS for hand fatigue, and video analysis of duration of exertion while in heavy pinch or power grip (table 2). Three methods were used to estimate ACGIH-TLV for HAL scores (10) by task for each individual and each hand. All three methods utilized the normalized peak force value previously described but differed in the type of repetition measure used. One method (A) utilized the observer-rated HAL scale, the second (B) utilized video-based total repetition rate, and the third (C) utilized the video-based repetition rate in heavy pinch or power grip. For each method, a time-weighted average HAL score was calculated for each individual.

Outcome variables

The primary outcomes were incident hand/wrist tendinoses in the right hand. Subjects became a case once they were diagnosed with any one of the possible 11 diagnoses of the hand and wrist (table 1). Once a subject was diagnosed with any tendinosis disorder they were censored; they could no longer become a case, even if they developed tendinosis in a different muscle.

Statistical analysis

Survival analysis was performed for all univariate and multivariate analyses using the Cox proportional hazards model with robust confidence intervals. Repetition and force specific exposure variables were divided into tertiles based on equal number of cases in high-, medium-, and low-exposure groups. The ACGIH-TLV for HAL was applied using standard cut-off points of 0.56 and 0.78, and the strain index was divided into a high- and low-exposure group based on standard cut-offs of 3 and 7, and an equal number of cases in each group. Exposure variables related to the outcome with a $P<0.2$ in the univariate analysis were analyzed further in multivariate models. Potential confounders were included in each multivariate model and sequentially removed and replaced. Variables that changed the hazard ratio (HR) >10% were retained in the final model. Though only gender consistently met this criterion, all models included adjustment for age and gender.

Results

Descriptive

The study population included 151 women and 262 men (table 3). The average age of participants was 38.6 years (SD=11.2). Thirty-nine participants had a medical condition that included diabetes, lupus, rheumatoid arthritis, or gout and 64 participants currently smoked. Only one woman was pregnant during the study and five were taking birth control pills. Low job strain was reported in 72% of the participants and 58% had worked at their job for more than five years.

Incidence rates

There was a total of 481.4 years of person time in the study. Four hundred and thirteen of the 450 individuals at baseline had follow-up data for up to 28 months (table 4). Thirty-seven individuals were not eligible to become incident cases because they were cases at baseline. There were 26 incident cases of right wrist tendinosis for an incident rate of 5.4 cases per 100 person-years. Some individuals had multiple specific wrist tendinoses at one time but were counted as just one case. Tendinosis of the right 1st dorsal compartment (de Quervain's tendinosis) had the highest overall incidence at 2.7 cases per 100 person-years (N=13).

The incidence rate (IR) of right wrist tendinosis was calculated for various demographic, health, and work psychosocial variables (table 3). The IR for the chair manufacturing plant (14.4) was substantially higher than that of the mushroom production plant (IR 7.8), or the stone manufacturing plant (IR 3.3). There were no incident cases of right wrist tendinosis at the dairy manufacturing plant.

Univariate analysis

Being female increased the risk (HR 4.80, 95% CI 2.01–11.45) of developing right wrist tendinosis as did being Hispanic, working day shifts and having a medical condition (table 3). Those who worked >5 years at their current job had a decreased risk of right wrist tendinosis.

Exposure variable univariate analyses are shown in table 5. HR for high normalized peak force and the % time spent in heavy pinch were elevated while the HR decreased with any increase in time spent in heavy power grip. Some of the repetition measures, such as the speed of work and repetition rate while in heavy grip, were slightly protective for both medium- and high-exposure groups. However, the HR for repetition rate for medium- and high-exposure groups while performing a light pinch and, to a lesser extent, a heavy pinch were elevated.

The correlations were moderate between the % time spent in heavy pinch and (i) the HAL scale (r=0.66), (ii) repetition rate while in heavy pinch or power grip (r=0.59) and (iii) total repetition rate (r=0.51).

Multivariate analysis

Direct measurement using normalized peak force from matching pinch and power grip measurements showed no change in risk in the medium-exposure group (HR 0.93, 95% CI 0.35–2.41) but a significantly higher increase in risk in the high-exposure group (HR 3.26, 95% CI 1.15–9.3) (figure 1). The % time in heavy pinch, as quantified using video analysis, showed an increasing risk of 1.60 (95% CI 0.6–4.24) and 1.81 (95% CI 0.66–5.0) for medium- and high-exposure groups, respectively. The HR for the % time in heavy pinch or power grip were 1.51 (95% CI 0.57–3.99) and 1.28 (95% CI 0.47–3.50) for medium- and high-exposure groups, respectively. For the % time in all pinch and power grip (heavy or light), the HR were protective for medium- (HR 0.83, 95% CI 0.33–2.07) and high- (HR 0.45, 95% CI 0.16–1.29) exposure groups.

The self-reported measure of force using the VAS for hand fatigue showed an increased risk of developing right wrist tendinosis for medium- (HR 1.75, 95% CI 0.61–5.01) and high- (HR 2.1, 95% CI 0.71–6.16) exposure groups (no figure). Direct measurement of tool weight showed reduced risk of wrist tendinosis for medium- (HR 0.02, 95% CI 0.01–0.11) and high- (HR 0.17, 95% CI 0.07–0.46) exposure groups.

Multivariate models comparing different methods for quantifying repetition, controlling for age and gender, are shown in figure 2. The HR for observer-rated HAL scale medium- and high-exposure groups were 0.97 (95% CI 0.28–3.45) and 1.02 (95% CI 0.41–2.54). HR for observer-rated speed of work were protective for medium- (0.22, 95% CI 0.05–0.98) and high- (0.67, 95% CI 0.27–1.65) exposure groups. For video-based total repetition rate (across all 5 hand postures), the HR were slightly protective for the medium- (0.95, 95% CI 0.36–2.48) and high- (0.69, 95% CI 0.26–1.85) exposure groups. The repetition rate during just heavy pinch or power grip had HR of 1.47 (95% CI 0.56–3.92) and 1.47 (95% CI 0.53–4.03) for the medium- and high-exposure groups, respectively.

Table 3. Univariate analysis: demographic and work psychosocial variables. [HR=hazard ratio; 95% CI=95% confidence interval.]

	N (right-side analysis)	Right-side cases	Controls	Incident rate	HR	95% CI	P-value
Gender	413	26	387				
Male	262	7	255	2.23	1.00		
Female	151	19	132	11.34	4.80	2.01–11.45	0.00
Age (years)	413	26	387				
<40 years of age	212	11	201	4.36	1.00		
≥40 years of age	201	15	186	6.54	1.54	0.72–3.31	0.27
Ethnicity	398	23	375				
Non-Hispanic	53	2	51	2.48	1.00		
Hispanic	345	21	324	5.45	2.44	0.53–11.37	0.26
Body mass index (kg/m^3)	406	26	380				
<30	265	18	247	5.77	1.00		
≥30 (obese)	141	8	133	4.95	0.89	0.39–2.07	0.79
Handedness	405	26	379				
Left-handed	14	0	14	0.00	1.00		
Right-handed	391	26	365	5.79	.	. .	.
Medical history	408	26	382				
No medical condition [a]	369	21	348	4.91	1.00		
Medical condition [a]	39	5	34	11.50	2.38	0.88–6.43	0.09
No diabetes	380	23	357	5.23	1.00		
Diabetes	27	3	24	10.28	2.04	0.59–7.04	0.26
No medication [b]	140	12	128	6.65	1.00		
Medication [b]	8	0	8	0.00	0.00	0.00–0.00	0.00
Smoking Status	408	26	382				
Never/previously smoked	344	22	322	5.61	1.00		
Currently smokes	64	4	60	4.93	0.87	0.29–2.64	0.81
Physical activity outside of work	398	24	374				
<1 hour/week	181	11	170	5.22	1.00		
≥1 hour/week	217	13	204	5.14	0.99	0.45–2.20	0.99
Overall Health Status	400	23	377				
Poor	115	8	107	6.02	1.00		
Fair or better	285	15	270	4.47	0.76	0.33–1.79	0.54
Educational Level	406	23	383				
Some or no highschool	289	16	273	5.12	1.00		
High school graduate or higher	117	7	110	4.36	0.81	0.28–2.30	0.69
Shift	405	25	380				
Swing/night/rotating shift	142	1	141	0.62	1.00		
Day shift	263	24	239	7.80	11.91	1.59–89.35	0.02
Job strain index	392	22	370				
Low job strain	280	15	265	4.62	1.00		
High job strain	112	7	105	5.21	1.10	0.46–2.64	0.83
Iso strain index	390	22	368				
Low iso strain	327	18	309	4.73	1.00		
High iso strain	63	4	59	5.32	1.15	0.40–3.35	0.80
Years at Job	413	26	387				
<2 years	85	5	80	5.49	1.00		
≥2–5 years	88	7	81	7.08	1.22	0.39–3.80	0.73
≥5 years	240	14	226	4.80	0.86	0.31–2.36	0.77
Job satisfaction	394	23	371				
Unsatisfied	31	1	30	2.59	1.00		
Satisfied	363	22	341	5.21	2.02	0.26–15.61	0.50
Job site	413	26	387				
Dairy manufacturing	48	0	48	0.00			
Chair manufacturing	32	6	26	14.41	1.00		
Mushroom manufacturing	160	15	145	7.80	0.62	0.20–1.94	0.41
Stone manufacturing	173	5	168	3.28	0.32	0.07–1.45	0.14

[a] Medical condition includes: lupus, gout, rheumatoid arthritis, diabetes, thyroid disease.
[b] Medications include anti-anxiety and anti-depressants.

Table 4. Incidence of wrist tendinosis disorders (N=413).

	28-month follow-up					
	Left side	Right side	Either side	Left-side incidence /100 person-years	Right-side incidence /100 person-years	Either side incidence /100 person-years
Total hand/ wrist tendinosis cases	17	26	31	3.73	5.40	5.84
Flexor tendinosis	7	11	16	1.42	2.24	3.27
Flexor carpi radialis tendinosis	3	7	9	0.61	1.42	1.83
Flexor carpi ulnaris tendinosis	2	0	2	0.40	0.00	0.40
Flexor digitorum tendinosis	2	5	6	0.40	1.01	1.21
Trigger finger	1	2	3	0.20	0.40	0.61
Extensor tendinosis	15	22	26	3.11	4.56	4.80
Dorsal compartment 1	12	13	16	2.47	2.68	2.89
Dorsal compartment 2	3	2	3	0.61	0.40	0.61
Dorsal compartment 3	3	6	6	0.61	1.23	1.23
Dorsal compartment 4	2	6	6	0.41	1.21	1.21
Dorsal compartment 5	0	0	0	0.00	0.00	0.00
Dorsal compartment 6	5	4	7	1.02	0.81	1.43
Intersection syndrome	0	0	0	0.00	0.00	0.00

The HR for heavy pinch repetition rate for medium- and high-exposure groups were 1.04 (95% CI 0.39–2.79) and 1.49 (95% CI 0.54–4.12) (no figure). The HR for the repetition rate while in heavy power grip were 0.87 (95% CI 0.28–2.7) and 0.62 (95% CI 0.21–1.88) for medium- and high-exposure groups, respectively, and for the repetition rate in any pinch (light and heavy pinch) were 1.66 (95% CI 0.63–4.38) and 0.76 (95% CI 0.27–2.09).

When adjusting the model of % time spent in heavy pinch for repetition as measured by observer-rated HAL scale, the HR increased for medium- (HR 2.27 95% CI 0.72–7.19) and high- (HR 3.42, 95% CI 0.9–13.01) exposure groups (figure 3). The results were similar when adjusting the same model using the repetition rate while in heavy pinch or power grip (medium group HR 2.75, 95% CI 0.33–23.17 and high group HR 4.13, 95% CI 0.35–49.1) or total repetition rate (medium HR 2.07, 95% CI 0.76–5.66 and high group HR 5.01, 95% CI 1.27–19.79).

When adjusting the various repetition models for force as measured by the % time spent in heavy pinch, the HR decreased substantially and were primarily protective (figure 4).

Results from analyses of four different composite measures of force and repetition are shown in figure 5. The strain index had a HR of 2.7 (95% CI 0.34–21.64) for the high-exposure group when using a cut-off value of 7 to separate low- and high-exposure groups. Due to missing data, this analysis included only 197 subjects (14 cases). When the same analysis was performed based on an equal number of cases in each

Table 5. Univariate analysis: time-weighted averages of exposure variables. [TLV=threshold limit values. Reps/min=repetitions per minute.]

	N (total	Cases	Controls	Cut-off values	HR	95% CI	P-value
Force measures							
Visual analog scale for hand fatigue	345	21	324				
Low	149	7	142	≤3.43	1.00		
Medium	80	7	73	>3.43 and ≤5.14	1.81	0.63–5.19	0.27
High	116	7	109	>5.14	1.87	0.63–5.52	0.26
% time light pinch	386	26	360				
Low	203	9	194	≤22%	1.00		
Medium	74	9	65	>22% and ≤46%	1.86	0.67–5.19	0.24
High	109	8	101	>46%	1.20	0.44–3.24	0.72
% time heavy pinch	388	26	362				
Low	154	9	145	≤9%	1.00		
Medium	87	9	78	>9% and ≤31%	1.87	0.74–4.72	0.19
High	147	8	139	>31%	1.70	0.60–4.83	0.32
% time light power grip	382	26	356				
Low	29	9	20	≤1%	1.00		
Medium	144	9	135	>1% and ≤7%	0.18	0.07–0.45	0.00
High	209	8	201	>7%	0.13	0.05–0.36	0.00
% time heavy power grip	360	21	339				
Low	99	9	90	≤1%	1.00		
Medium	59	5	54	>1% and ≤3%	1.01	0.34–2.96	0.99
High	202	7	195	>3%	0.45	0.16–1.25	0.12

(cont'd)

Table 5. Continued

	N (total	Cases	Controls	Cut-off values	HR	95% CI	P-value
% time heavy pinch or power grip	389	26	363				
Low	130	9	121	≤10%	1.00		
Medium	84	9	75	>10% and ≤32%	1.43	0.54–3.78	0.47
High	175	8	167	>32%	1.02	0.38–2.73	0.97
% time all pinch or power grip	389	26	363				
Low	89	9	80	≤59%	1.00		
Medium	124	11	113	>59% and ≤65%	0.95	0.38–2.34	0.90
High	176	6	170	>65%	0.46	0.16–1.32	0.15
Tool weight (kg)	325	21	304				
Low	63	12	51	≤0.6	1.00		
Medium	175	2	173	>0.6 and ≤0.91	0.06	0.01–0.28	0.00
High	87	7	80	>0.91	0.47	0.18–1.21	0.12
Normalized peak force	360	26	334				
Low	140	9	131	≤1.49	1.00		
Medium	192	9	183	>1.49 and ≤4.92	0.82	0.32–2.08	0.67
High	28	8	20	>4.92	4.68	1.71–12.77	0.00
Repetition measures							
Hand activity level (HAL) scale	354	24	330				
Low	139	13	126	≤3.33	1.00		
Medium	45	3	42	>3.33 and ≤4.41	0.78	0.21–2.87	0.70
High	170	8	162	>4.41	0.81	0.28–2.34	0.70
Efforts/minute	156	13	143				
Low	64	12	52	≤13.33	1.00		
High	92	1	91	>13.33	0.05	0.01–0.40	0.01
Speed of work	354	24	330				
Low	108	14	94	≤2.67	1.00		
Medium	68	2	66	>2.67 and ≤3.06	0.22	0.05–1.00	0.05
High	178	8	170	>3.06	0.45	0.18–1.14	0.09
Reps/min: heavy pinch or power grip	389	26	363				
Low	134	9	125	≤4.52	1.00		
Medium	96	9	87	>4.52 and ≤19.2	1.40	0.54–3.59	0.49
High	159	8	151	>19.2	1.29	0.47–3.49	0.62
Reps/min: total (all grips)	389	26	363				
Low	117	9	108	≤38.88	1.00		
Medium	97	9	88	>38.88 and ≤47.24	1.40	0.57–3.43	0.46
High	175	8	167	>47.24	0.93	0.36–2.41	0.89
Posture and composite exposure measures							
Hand posture (0–5)	353	24	329				
Low	137	9	128	≤2	1.00		
Medium	41	7	34	>2 and ≤3	3.04	1.09–8.48	0.03
High	175	8	167	>3	0.95	0.36–2.50	0.91
HAL TLV (HAL Scale)	342	24	318				
Low	165	8	157	≤0.56	1.00		
Medium	132	10	122	>0.56 and ≤0.78	2.24	0.86–5.85	0.10
High	45	6	39	>0.78	3.99	1.40–11.33	0.01
HAL TLV (video: total repetitions)	351	25	326				
Low	262	10	252	≤0.56	1.00		
Medium	57	11	46	>0.56 and ≤0.78	5.84	2.51–13.62	0.00
High	32	4	28	>0.78	4.49	1.41–14.31	0.01
HAL TLV score (video: heavy pinch or power grip)	351	25	326				
Low	262	10	252	≤0.56	1.00		
Medium	57	11	46	>0.56 and ≤0.78	5.84	2.51–13.62	0.00
High	32	4	28	>0.78	4.49	1.41–14.31	0.01
Strain index score (case cut-off)	197	14	183				
Low	136	6	130	≤40.5	1.00		
High	61	8	53	>40.5	4.97	1.82–13.58	0.00
Strain index score	197	14	183				
Low	46	1	45	≤7	1.00		
High	151	13	138	7	4.69	0.67–32.56	0.12

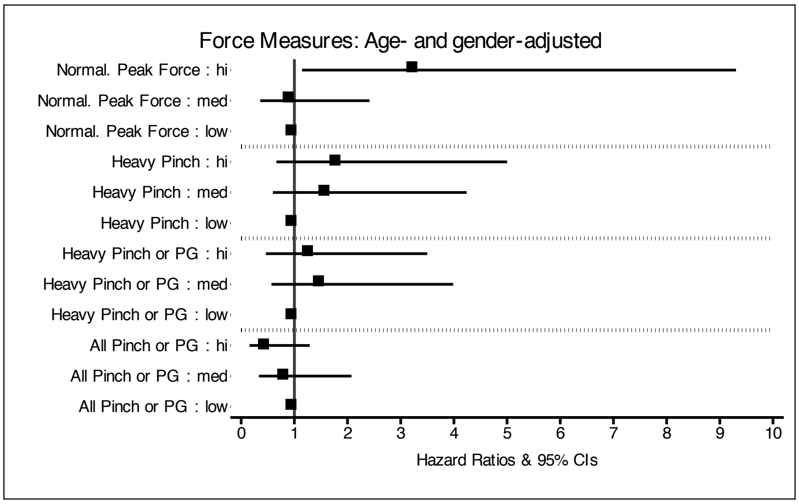

Figure 1. Multivariate analysis adjusted for age and gender: hazard ratios for right side wrist tendinosis and normalized peak force (normalized matching pinch and power grip % MVC), the % time spent in various hand grips including heavy pinch, heavy pinch or power grip (PG), and all pinch or power grip.

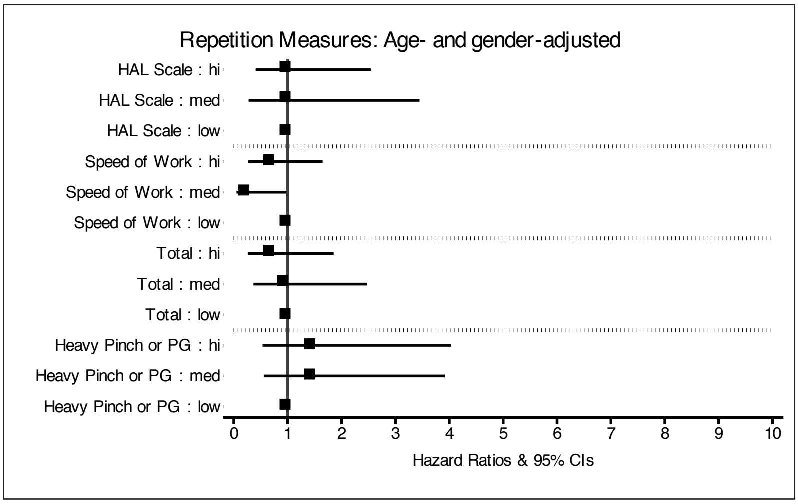

Figure 2. Multivariate analysis adjusted for age and gender: hazard ratios for right side wrist tendinosis and different measures of repetition including observer-rated HAL scale and speed of work and video analysis of the repetition rate while in any grip posture (total), and heavy pinch or power grip (PG).

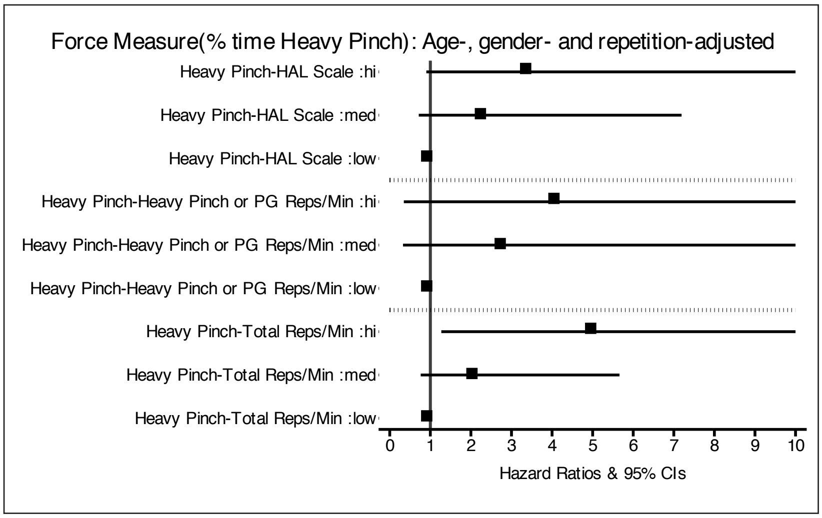

Figure 3. Multivariate analysis adjusted for age, gender and repetition: hazard ratios for right side wrist tendinosis and % time spent heavy pinch adjusting for repetition as measured by observer-rated HAL scale score, video analysis of heavy pinch or power grip repetition rate (reps/min), and video analysis of total repetition rate (reps/min).

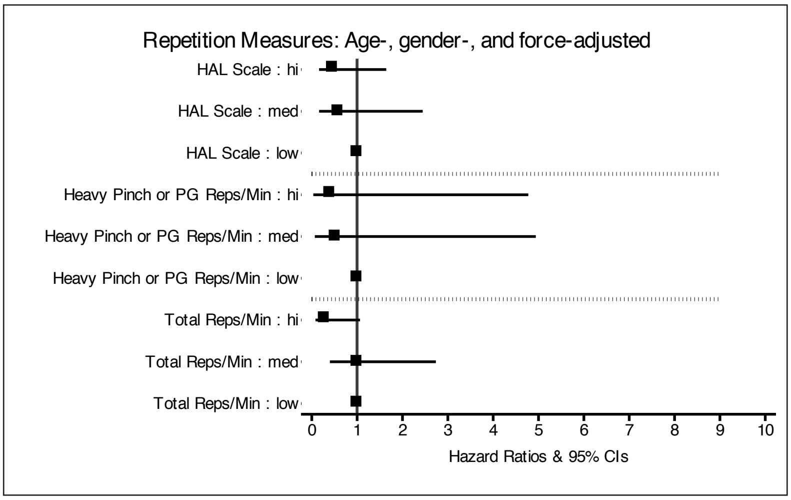

Figure 4. Multivariate analysis adjusted for age, gender and force: hazard ratios for right side wrist tendinosis and exposure to repetition measured in 3 different ways: observer-rated HAL scale score, video analysis of heavy pinch or power grip repetition rate (reps/min), and video analysis of total repetition rate (reps/min), adjusting for percent time in heavy pinch.

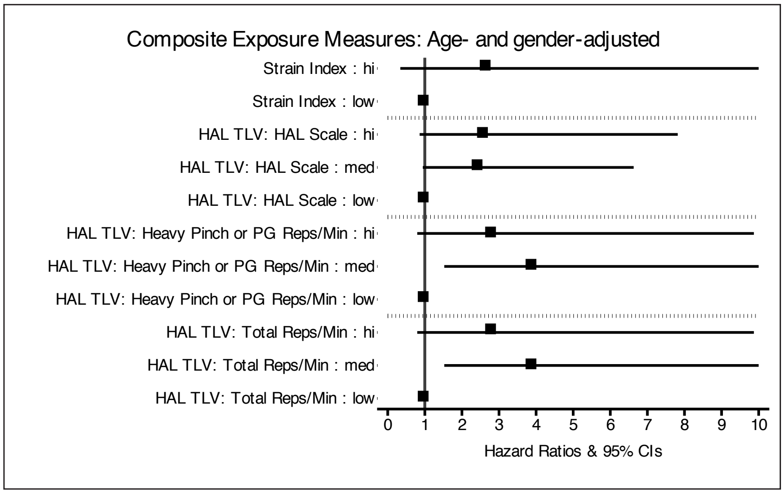

Figure 5. Multivariate analysis adjusted for age and gender: hazard ratios for right side wrist tendinosis and composite measures including the Strain Index and the ACGIH-TLV for HAL (HAL TLV) using direct measures of force combined with three different methods for calculating the Hand Activity Level scale: (A) observer-rated; (B) video analysis of heavy pinch or power grip (PG) repetition rate (reps/min); and (C) video analysis of total repetition rate (reps/min).

group (cut-off 40.5), the HR was higher (4.05, 95% CI 1.26–12.99).

Three measures of repetition were used to calculate three different ACGIH-TLV for HAL scores and were assessed in multivariate models controlling for age and gender. The HR using the observer-rated HAL scale were 2.5 (95% CI 0.95–6.63) and 2.59 (95% CI 0.86–7.82) for medium- and high-exposure groups, respectively. When using either the video-based heavy pinch or power grip repetition rate, or the total repetition rate to calculate the ACGIH-TLV for HAL, the HR were identical, 3.95 (95% CI 1.52–10.26) and 2.8 (95% CI 0.8–9.87) for the medium- and high-exposure groups, respectively.

Discussion

Non-occupational and psychosocial factors

Female gender, Hispanic ethnicity, and working day shifts were associated with higher hazards for wrist tendinosis. Having a medical condition such as diabetes, thyroid disease, rheumatoid arthritis, lupus, or gout was also a predictive factor in this study; however, except for diabetes, the number of cases were small. There was not enough power in this study to determine the effects of each medical condition alone, nor was there enough power to determine if pregnancy, the birth control pill or anxiety/depression medication were associated with an increased incidence of wrist tendinosis. Body mass index was not significant predictor. In the literature, psychosocial factors have had inconsistent associations with upper-extremity MSD (7, 22). Job control as measured by demand, control, and strain through the job content questionnaire was not a significant predictor in this study. Hand dominance had very few cases in comparison groups limiting the precision of the estimates and an ability to make inferences from the findings. Those who worked >5 years at their current job had a slightly decreased risk of right wrist tendinosis compared to those who worked <5 years. This inverse relationship suggested that workers with greater susceptibility to tendonosis were more likely to change jobs or leave the workplace.

Force measures

The time spent in heavy pinch was the most significant predictor of wrist tendinosis, and the relationship followed an exposure–response pattern. When adjusting the model for time spent in heavy pinch with total repetition rate (figure 3), the HR increased nearly two-fold for both the medium- and high-exposure groups indicating that high pinch force alone is an important predictor of right wrist tendinosis. The % time in heavy pinch appears a robust risk factor given that the pattern is preserved after adjusting for different measures of repetition including the observer-rated HAL scale and the repetition rate in heavy pinch or power grip (figure 3). This strong association with heavy pinch may be associated with the higher incidence of tendinosis of the abductor pollicis longus (deQuervain's tendinosis), a tendon that is very active during pinch.

The risk of developing wrist tendinosis decreased as more time was spent in heavy power grip (% time spent heavy pinch or power grip) or light pinch or light power grip (% time spent in all pinch or power grip) as shown in figure 1. Based on modeling, the forces applied to the forearm flexor and extensor muscles during a power grip are substantially less than with a pinch grip (23) and this may account for the differences in risk. An interesting finding was the similar HR for medium and high exposure groups for the % time in heavy pinch and the self-reported VAS for hand fatigue. This relationship was not seen at baseline in the high-exposure groups (unpublished data) and may indicate the eventual inability for those with wrist tendinosis to remain in high-exposure jobs. Additionally, the direct measure of normalized peak force, which was derived from force matching in pinch and power grip, was strongly associated with right wrist tendinosis in the high-exposure group. Unexpectedly, a higher object tool weight showed a protective relationship with right wrist tendinosis, however, the smaller sample size reduces the precision of this estimate and makes it difficult to draw conclusions.

Repetition measures

Several different methods of quantifying repetition were assessed in this study: observer-rated scales of the HAL repetition score, observer-rated speed of work, and video-based quantification of heavy pinch or power grip and total (all hand postures) repetition rates (figure 2). Regardless of the method used, repetition showed no predictive value for right wrist tendinosis. After the models were adjusted for force, measured by the % time spent in heavy pinch, a protective pattern for repetition emerged (figure 4). This was a surprising finding given the independent effect of repetition observed in cross-sectional studies (1, 10). Two differences with prior studies were the prospective design of this study and the blinded, detailed method for measuring repetition from video. The hand repetition rates at the sites studied were not narrow but covered a broad range as indicated by the interquartile range of 37.1 and 61.9 repetitions per minute (median 44.6).

Composite exposure measures

The ACGIH-TLV for HAL and the strain index are tools used by safety professionals in the workplace to quantify risk for distal upper extremity disorders based on exposure to more than one biomechanical risk factor such as force, repetition, and posture. The ACGIH-TLV for HAL quantifies exposure to force and repetition for mono-task jobs. In this study, a time-weighted average methodology was applied to account for multi-task jobs. This time-weighted average TLV for HAL was a good predictor of wrist tendinosis, with a 2.5–4 fold increase in HR. However, there was no difference in HR between the medium- (>0.56=action limit) or high- (>0.78=TLV) exposure groups indicating a possible threshold effect at the moderate level. The value of the ACGIH-TLV for HAL was robust as indicated by similar findings when using three different methods to quantify repetition when calculating ACGIH-TLV for HAL scores. This may be important for practitioners since the observer-rated HAL repetition scale is quicker and easier to apply than the video analysis methods used to quantify repetition.

The strain index is another summary measure that is often utilized in the field, although with six factors to measure it is somewhat more time consuming to use than the ACGIH-TLV for HAL. The HR for the strain index was increased with scores >7, a cut-off point commonly used in the literature. When using 7 as a cut-off point, the strain index nearly perfectly predicted all those who developed wrist tendinosis (13 of 14), however it was not very specific in identifying those who were not at risk for developing wrist tendinosis since 151 of the 197 workers analyzed had a score >7. When using a cut-off value of 40.5 (based on an equal number of cases in low and high exposure groups) the specificity of the strain index improved. Unfortunately, the smaller number of subjects with the full strain index data makes any inferences difficult.

Limitations

While the study design had important strengths, such as the prospective design and the individual-based blinded assessment of exposures and outcomes, some limitations should be noted. Self-reported worker estimates of weekly time spent on each task were important multipliers for calculating the time-weighted average exposures. There may be errors in estimates; however, these errors would likely be non-differential and bias the findings toward the null.

In addition, in spite of the large sample size, the number of cases of right wrist tendinosis was relatively small so it is possible that some of the exposure variables that were not statistically significant with the outcome were a result of inadequate power. Additionally, when comparing the exposure group cut-offs for the % time spent in heavy pinch (31%) and heavy power grip (3%), it is clear that this population had greater exposure to heavy pinch. Therefore, caution should be taken when interpreting the statistically non-significant but possible protective effect seen with more time spent in heavy power grip.

Seven people with incident wrist pain did not self-ascribe their pain to work exposures and were therefore not examined and could not become a case. Using worker perception of work-relatedness pain as a screening criterion may be too restrictive. Some of them could have been diagnosed with wrist tendinosis. However, this would result probably to only 1–2 additional cases, a number unlikely to change the main findings of this study.

Finally, self selection of workers into more demanding jobs is a possibility. However, there was some evidence observed for bias in the opposite direction, with self-selection of injured or more fatigued workers into less demanding jobs. This healthy worker survivor effect would bias the results downward, thus underestimating associations, rather than explain the positive associations that were observed.

Concluding remarks

In conclusion, the % time spent in heavy pinch is an important risk factor for the development of wrist tendinosis. The exposure assessment method used to quantify exposure to heavy pinch was unique in that it quantified the amount of time spent over a threshold pinch force of 1 kg versus requiring a precise direct measurement of force such as force matching, a technique that can have limitations depending on the worker and the specific instructions provided (16). Previous cross sectional studies have indicated an association with hand force (power grip and pinch), repetition, and wrist tendinosis. This study highlights the singular importance of duration of exposure to high force pinch in the development of wrist tendinosis.

This study is an important contribution to our understanding of causal factors for wrist tendinosis since it is one of the few prospective studies using individualized exposure assessment methods to evaluate the risk of wrist tendinosis in the work place. The findings may provide practitioners with data to improve programs for preventing workplace wrist tendinopathies.

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