A Longitudinal Study of Wrist Tendinosis in Blue Collar Workers.

by

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Professor David M. Rempel, Chair

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Abstract

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Introduction

Wrist tendinosis is a common distal upper extremity disorder that can be work-related. Workplace cross-sectional (Franzblau, 2005) and prospective studies (Leclerc 2001, Thomsen 2007) have linked distal upper extremity pain and disorders to forceful or repetitive hand exertions, but the associations are not consistent across studies. A study rigorously assessing both workplace physical exposures and wrist tendinosis would be useful in clarifying the dose-response relationships which could provide guidance for prevention. This dissertation presents the results from a prospective study of right wrist tendinosis among blue-collar workers, and includes a comparison of exposure measurement methods, a cross-sectional analysis of the cohort at baseline, and a prospective analysis of the association between exposure to physical risk factors and the subsequent development of right wrist tendinosis during a 28 month follow up period.

Methods

Workers (N=450) at four manufacturing industries participated in this study and were followed up for up to 28 months (n=413) with questionnaires and physical examinations every 4 months to identify incident cases of right wrist tendinosis. Workers were eligible to participate if they performed primarily hand intensive manual (not office) work and were not assigned to more than four tasks. Exposure assessment was based on job evaluations by experienced ergonomists and video analyses of tasks. A variety of self-report, observer-rated, direct measure, and video analysis methods were used to quantify workers exposure to force and repetition at baseline. Detailed video analysis determined percent time the right hand applied a high force pinch (> 1 kg-force) or power grip (>4kg-force) for each task. No load and low force pinch (<= 1 kg-force) and grasp (<=4kg-force) were also determined. Repetition was quantified by observer-rated hand activity level (HAL) scale and video analysis of repetition rate (reps/min) in heavy or light grip or pinch postures. A comparison of each worker's longest duration task was performed using the Pearson correlation. All exposure variables were measured on the individual task level and time weighted averages for overall exposure were calculated for each

worker. Logistic regression was used to model the log odds of tendonitis at baseline, as a function of exposure variables and relevant confounders. Survival analysis using the Cox Proportional Hazards Model was used to assess the relationship between individual and workplace factors and wrist tendinosis for all prospective data. Force, repetition, and composite measures with $p<0.2$ in the univariate analyses were evaluated in multivariate models. Potential covariates with $p<0.2$ in the univariate analysis or a correlation ($r>0.3$) with the exposure variable of interest were included in the multivariate model and consecutively removed and replaced to assess for confounding.

Results

There were 37 cases of right wrist tendinosis at baseline and 26 incident cases during the 28-month follow up. Analysis of exposure measures revealed correlations ($r=0.63$) between the visual analog scale (VAS) for hand fatigue and the rate of perceived exertion (RPE). The HAL repetition scale and the Speed of Work observer-rated scales were moderately correlated ($r=0.65$). The scales' stronger correlation with the percent time spent in grip ($r= 0.41$) versus pinch ($r=-0.25$) could be based on the difficulty discerning distinct repetitions while in pinch.

For the prospective analysis, job satisfaction, smoking status, annual income, BMI, education level, job strain, and general health were not significant predictors in the univariate analysis and were therefore not included in multivariate models. Age, gender (HR= 4.8; 95%CI: 2.01-11.45), ethnicity, medical condition, and shift were all assessed for confounding, though only age and gender remained in the final models. The two most predictive models included the percent time spent in high force pinch adjusting for repetition (HR = 2.27; 95% CI: 0.72-7.19 and HR=3.42; 95%CI: 0.9-13.01 for medium and high groups), and the ACGIH TLV Hand Activity Level (HR = 3.95; 95% CI: 1.52-10.26 and HR=2.8; 95%CI: 0.8-9.87 for medium and high groups).

Discussion

In this prospective study, the workplace factors predicting wrist tendinosis were time weighted average values of the percent time spent performing a high force pinch, the normalized peak force, and the ACGIH TLV Hand Activity Level. The percent time spent in power grip was not a significant workplace predictor, nor were any of the measures of repetition. Individual factors including job satisfaction, general health, and BMI were not significant predictors, but gender was. The most predictive measure of force was the video of the work task quantified for the percent time spent in high force pinch; the relationship followed a dose-response pattern. Based on this study, in order to prevent wrist tendinosis, it is recommended that the tasks of workers performing repetitive, hand intensive tasks be designed so that less than 10% of the task time requires pinch force greater than 1 kg.

This dissertation is dedicated to my husband
James Nicholas Adamson,
and my children
Ava Dorothea and James Ian Adamson.

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Introduction

Literature Overview

Historically, work related upper extremity musculoskeletal disorders (UEMSDs) have comprised a significant portion of the number and cost of injuries in the workplace. Upper extremity musculoskeletal disorders 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 UEMSDs 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 $6977 and up to $8000 per case (Silverstein et al., 1986; Webster, 1994) with a median cost of $824, indicating that many distal upper extremity disorders are severe and costly. In fact, UEMSD costs due to lost time at work, referred to as indemnity costs, have accounted for up to 65% of overall costs (Webster, 1994). The annual incidence rate for distal upper extremity disorders has been reported at 2.6 per 100 workers with one third of the cases and half of lost work time due to musculoskeletal disorders from overuse (Silverstein et al., 1998; Armstrong, 1986). The overall cost of UEMSDs in the United States has been estimated up to 6.5 billion dollars per year (Silverstein et al., 1998). Furthermore, a study by Morse et al. (2005) estimated that only 6-8% of work related UEMSDs are reported indicating that the overall problem has been more severe than what claim data indicates. The problem of underreporting UEMSDs 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 (Fan et al., 2006). The problem of work related UEMSDs has been and continues to be widespread and costly.

Wrist flexor and extensor tendinopathies are common work related distal upper extremity disorders. Tendons connect muscles to bones and inflammation or microtears of a tendon cause tendinopathy, also commonly referred to as tendinosis. Inflammation and microtears of tendons are common in overuse injuries. The result is pain, stiffness, and loss of strength. Continued use of the afflicted tendon creates discomfort and further irritation, and, without proper rest or exposure reduction, can result in loss of function.

There are five physical risk factors (Armstrong et al., 1987; Descatha et al., 2007; Tanaka, 2001) associated with UEMSDs including force, repetition, posture, contact pressure, and/or environmental hazards, such as low temperatures or vibration. Of these, force, repetition, and posture are the most common physical risk factors in the workplace, but it should be noted that these risk factors also occur outside of work. Silverstein et al. (1986) found that high hand forces, that is, forces greater than 44.1N (4kg) for power grip and greater than 8.9N (1kg) for pinch grip posed a significant risk. Other studies have found that 'high hand force' is an independent risk factor of hand and wrist tendinosis (Armstrong, 1987; Leclerc, et al., 2001; Silverstein et al., 1986; Thomsen et al., 2007). Repetitive motions, defined by tasks with wrist or hand exertions less than every 30 seconds, are associated with increased prevalence of distal upper extremity (hand and wrist) discomfort and tendinosis with an odds ratio ranging from 1.17 to 3.23 (Latko et al., 1999; Silverstein et al., 1987; Silverstein et al., 1986). Posture, specifically non-neutral joint positions, has also been identified as a risk factor for UEMSDs (Armstrong et al., 1987). Kutsumi et al. (2005) demonstrated that wrist position significantly affects extensor pollicis brevis tendon gliding resistance and likely contributes to the development of wrist extensor tendinosis. 'Extreme awkward postures' has been defined by a joint position being greater than 50-60% of total joint range from neutral and moderate awkward postures has been defined by being 20-40% from neutral (Roquelaure et al., 2002). For the wrist, moderate to extreme awkward posture is described by approximately 18 to 35° of extension, 20 to 40° of flexion, 5 to 10° of radial deviation and 7 to 15° of ulnar deviation.

While individual physical risk factors have been shown to be associated to UEMSDs, numerous studies also indicate that combinations of these same risk factors are related to even higher risk. Silverstein et al (1987) found that the odds ratio for carpal tunnel syndrome in highly repetitive jobs compared to low repetition jobs, regardless of force, was 5.5. The odds ratio increased to 15.5 for jobs with combined exposures to high force and high repetition when compared to jobs with low force and low repetition. Knox and Moore (2001) found that the odds ratio could be as high as 50 when exposure to high force, repetition and awkward posture coexisted in a job. Several authors have proposed combining individual risk factors in formulas or indices (e.g., ACGIH Hand Activity Level Threshold Limit Value, Moore-Garg Strain Index) that may improve the prediction of UEMSDs. However, these indices have been tested in very few prospective studies for wrist tendinosis (Knox & Moore, 2001).

Additionally, although crude relationships between repetition, force, posture and musculoskeletal disorders are known, little is known about the dose-response relationship between these individual risk factors and UEMSDs, or their combined effect. In fact, there have not been any rigorous prospective studies to date that have assessed casual factors for wrist tendinosis. By identifying a clear relationship of causal factors, and a threshold of individual and/or combinations of physical risk factors that cause wrist tendiosis, guidelines and policies can be developed to prevent them from occurring in the workplace.

Specific Aims

Aim 1: Determine the relationship between different methods of quantifying workplace exposure to force and repetition.

Aim 2: Describe the association between individual and combinations of physical risk factors and the prevalence of wrist tendinopathies (cross-sectional analysis) among 450 blue collar workers who perform hand intensive work.

- Aim 2a: Describe the prevalence of right wrist tendinopathies among 450 production workers in four different industries and describe the differences between subgroups defined by gender, ethnicity, age, socioeconomic characteristics, and work psychosocial factors.
- Aim 2b: Estimate the associations between time weighted average measurements of force, repetition, and posture and wrist tendinopathies, controlling for potential confounders.
- Aim 2c: Estimate the association between time weighted average measurements of the HAL-TLV and Strain Index and right wrist tendinopathies, controlling for potential confounders.

Aim 3: Estimate the associations between individual and combinations of physical risk factors and the incidence of wrist tendinopathies (prospective analysis) among 413 blue collar workers who perform hand intensive work.

- Aim 3a: Describe the incidence of right wrist tendinopathies among 413 production workers in four different industries and describe the differences between subgroups defined by gender, ethnicity, age, socioeconomic characteristics, and work psychosocial factors.
- Aim 3b: Estimate the associations between time weighted average measured values of force, repetition, and posture and wrist tendinopathies, controlling for potential confounders.
- Aim 3c: Estimate the association between time weighted average estimates of the HAL-TLV and Strain Index and wrist tendinopathies, controlling for potential confounders.

Data Collection Methods

Study Participants and Procedures

Participants. This was a 28-month prospective study assessing incidence and predictive factors for work related upper extremity disorders. Workers were eligible to participate if they performed primarily hand intensive manual (not office) work and were not assigned to more than four tasks. Exclusion criteria included employees who had worked for their current employer less than three months, did not expect to be working for their current employer for at least one year, or spent more than 25% of their time on a forklift or a computer. This analysis includes data from 450 workers. Of these, 413 had follow-up data from questionnaires and physical examinations completed every 4 months for up to 28 months. This dissertation evaluated the subset of data that was related to wrist pain or wrist tendinopathies.

Baseline Information. All participants were administered a baseline questionnaire via interview that assessed their job parameters, previous employment history, work organizational factors, and pain in various upper body regions including the hand/wrist region. The questionnaire 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 to be work related, AND the individual had a pain of 5 or greater on a 10 point scale in the past seven days, or had taken pain medication (including over the counter medication) for at least 2 of the past 7 days.

Physical exam maneuvers and diagnosis criteria for 11 work related upper extremity disorders of the wrist were modified from prior studies (Gerr et al., 2002; Rempel et al., 2006) (Table 1) and are grouped into wrist extensor and flexor tendinopathies. A licensed physical therapist completed all physical exams. Data on positive symptoms/maneuvers and diagnoses were recorded.

Periodic Follow Up. Subjects were administered a periodic questionnaire every 4 months via interview. The periodic questionnaire collected information on job changes such as changes in shift, overtime, duties, stress, and other psychosocial measures. Additionally, pain levels and parasthesias in the hand/wrist region were assessed, as were functional questions regarding work ability, work modifications, medication use, and health care. 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.

Exposure Assessment. Job title and primary work tasks were assessed for all workers and confirmed during an in depth individualized exposure assessment. The weekly hours for each task (up to 4 tasks) was estimated by each participant during recruitment and confirmed during baseline data collection and during the in depth individualized exposure assessment. The individualized exposure assessment was completed for 295 of the 450 subjects. The exposure assessment followed the methods of Bao et al., (2006) and Bao & Silverstein (2005) and has been demonstrated to provide the most accurate 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 were imputed based on the median values of the participants who performed the same tasks. 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 (e.g., $x_{twa}=\Sigma$ ((task duration per week/total working time per week)*exposure value)). An individual's peak value for a given exposure variable was the highest measurement across their tasks (up to 4).

Field Assessment. 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 hand activity level and the strain index were measured via observation. These included the HAL repetition scale, the duration of exertion, the efforts per minute, and the speed of work (Table 2). Hand tool weight was measured. The peak grip force was the highest force exerted by the hand and could have included grip, using the hand as a hammer, or exerting a push or pull. Matching pinch and grip forces were estimated via force gage by simulating an activity with a grip or pinch dynamometer in the position of hand force exertion. The percent of maximum voluntary contraction in pinch or grip was the matching grip or pinch force divided by the maximum voluntary contraction measured in the same posture, multiplied by 100.

Video Analysis. Approximately ten minutes of video were recorded for each task of each individual. The video was recorded during typical work activities for that task. The date and time of each video was recorded. 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 (MVTA) (Yen, 1995). During the video analyses, the force measurements collected in the field were used to categorize the hand posture for each frame as being engaged in no load (fingers or palm in no contact with any objects), light pinch(<=1kg), significant pinch(>1kg), light grip(<=4kg), and significant grip(>4kg) (Bao & Silverstein, 2005). A pinch was defined as a load that was primarily located on the fingers, unevenly distributed between the palm and the fingertips, or a pseudo-power grip (a grip around a thin object). A grip was defined as a load that was evenly distributed between the palm and the fingertips or primarily located on the palm. The percent time that the hand was in each posture was calculated by summing its number of frames and dividing it by the total number of frames observed for that task. The percent time spent in all force pinch and grip postures was the sum of the percent time spent in light pinch, heavy pinch, light grip, and heavy grip. Other summation values included the percent time spent in any pinch (heavy and light), any grip (heavy and light), any heavy hand posture (pinch and grip), and any light hand posture (pinch and grip).

Additionally, the number of wrist exertions in each hand posture provided a total and posture specific repetition rate (reps/min) for each video analyzed. The definition of an exertion was either a forceful movement of the wrist or fingers, (wrist extension/flexion, finger extension/flexion) or a change in the defined load of the hand or fingertips. Total repetitions per minute was the sum of exertions in all five hand postures including no load, light pinch, heavy pinch, light grip, and heavy grip. Other summation values include the repetition rate per minute in any pinch (heavy and light), any grip (heavy and light), any heavy hand posture (pinch and grip), and any light hand posture (pinch and grip).

If the hand was not visible in a frame, the posture was allocated to a 'no data' category and not included in the overall assessment of percent time or number of exertions in different hand postures. Both hands were evaluated separately.

Measures

Demographic Variables. 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 musculoskeletal diseases of the neck, low back and upper extremity was also assessed. Current and previous smoking status and medication use was recorded. The time spent engaging in different sports and other upper extremity intensive activities was assessed via interview and ultimately summed together to provide the total number of hours per week engaged in any hand intensive activity outside of work. General health was assessed via interview on a five-point scale (SF-36).

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

Work Organizational Factors. Information on work psychosocial factors was collected at baseline using the Job Content Questionnaire (Karasek et al., 1998). 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.

Hand/Wrist Musculoskeletal History. At baseline and every four months afterwards, discomfort in the hand and wrist region that lasted one week or longer or occurred three times in the past twelve or four months, respectively, triggered a more thorough interview. The symptoms, pain, work relatedness, treatment history, and impact on work were assessed via interview for any person having hand or wrist discomfort in the past year (baseline questionnaire) or the past four months (periodic questionnaire).

Exposure Variables. The duration of common activities such as driving, lifting, standing, etc. was assessed via interview at baseline. A job level self-rating of hand activity level and overall rate of perceived exertion was assessed via interview. Force measurements included those from self-report, observer-rated, direct measurement, and video motion analysis procedures. Self-report measures of force included the task specific rate of perceived exertion (RPE) and the task and side specific visual analog scale (VAS). Observer-rated measure of force included the duration of exertion ranging from 0 to 80% of total cycle time. Direct measures of force included matching power grip and pinch forces measured in the posture of use, then estimated as the percent of maximum voluntary contraction (MVC). The percent MVC was calculated by dividing the average of three force matching measurements for position-specific peak pinch/grip (Bao & Silverstein, 2005) by the individuals, or gender specific, maximum contraction norms in the position of use. The video analyses provided the percent time spent in the 5 hand postures for each task as well as summation values of any pinch, any grip, any heavy hand posture, any light hand posture, and all heavy and light hand postures.

Repetition. Observer-rated repetition measurements included the HAL scale rating (0 to 10 scale), the speed of work rating (0 to 5 scale), and the efforts per minute (0 to 20 scale). From the video analysis, the repetition rate for all five hand postures and the summation of postures were used in the analysis.

Calculated Risk Assessment Scores for Exposure to Multiple Risk Factors. Bilateral ACGIH Hand Activity Level (HAL) Threshold Limit Values (TLV) (Latko et al., 1999) including HAL scale, normalized peak force, and Moore-Garg strain index components (Moore & Garg, 1995) including exertion, duration of effort, repetition, speed of work, and posture were assessed for each task during the in depth exposure assessment. The participants rated perceived exertion of peak hand force using the Borg CR10 Scale (Borg, 1982) and the Visual Analog Scale. Individual normalized peak force was calculated by using the percent of maximum voluntary contraction (MVC) required for each task normalized to a 0 to 10 scale. Three different ACGIH-TLV for Hand Activity Level scores were calculated by task for each individual with exposure data. All three scores utilized the normalized peak force values but differed in the type of repetition measure included. The first score utilized the observer-rated HAL scale, the second score utilized video based repetition rate in all hand postures and the duty cycle in heavy pinch and grip postures, and the third score utilized the video based repetition rate and duty cycle in heavy pinch and grip postures.

The Strain Index (SI) was calculated from observer-rated values for speed of work, and posture, self-report identification of task duration and intensity of effort using the Visual Analog Scale for hand fatigue.

Outcome Variables. The primary outcome measure was the prevalence or incidence of right wrist tendinosis, which included the diagnosis of tendinosis at any of the four different flexor tendons or pulleys, or seven different extensor tendons or tendinous intersections at the wrist. Once a subject was diagnosed with any one of eleven specific wrist tendinoses, they could no longer become a wrist tendinosis case.

Disability and Quality of Life. Questions on the effects of ones injury on function was assessed via interview at baseline. Information on how the injury affected ones ability to do their job both in quality, technique, pace, and overall duration was collected. Additionally, questions on drowsiness, physical exhaustion, mental exhaustion, and the extent that discomfort interfered with normal social activities or activities of daily living were assessed on a 5-point scale.

Cohort Summary

Work Sites

Site 1 manufactured dairy products including milk, cheese, yogurt and ice cream. Milk was transported from regional dairy farms to the site via large trucks. Once the milk was pumped into the plant, various production lines were set up to produce different products. Machine operators were in charge of running the production lines, clearing jams, and basic cleaning throughout production. Additionally they could be in charge of adding ingredients to the production line. Once the product was produced and packaged, wet and dry order selectors pulled product from storage freezers or refrigerators and palletized them for shipment.

Site 2 manufactured various types of office chairs ranging from basic computer workstation chairs, to high-end executive chairs, and casual meeting room seating. Large rolls of fabric were spread out and secured on cutting tables where a laser machine cut patterns from the fabric. Sewers used industrial machines to sew pieces of fabric together to make chair covers. Concurrently, wooden forms were glued to special foam pads. The covers went to the assembly area where they were placed over the reinforced foam pads. 'Stringers' would secure the covers over the wooden supports using thread. Next, assembly workers added various fittings and pieces to build out the stem, arms, base, and various adjustments of the chair. Packers then lifted the chairs into boxes for shipping. Boxes were moved via forklift to trucks for transport. All chairs were made to spec.

Site 3 grew, harvested, and packaged white and portabella mushrooms. Large narrow rooms were filled with 'growing beds' stacked four levels high. Large amounts of fertilized dirt was prepared outdoors then placed on the beds with mushroom spores. After a short duration (1-7 days) the white and portabella mushrooms were ready for harvest. 'Pickers' would climb up and between 'growing beds' to reach the mushrooms, pull them out of the dirt, then trim the bases and place them into bins. Supervisors collected and weighed the bins then delivered them to the packaging line. Washers were in charge of washing mushroom bins. 'Packers' placed mushrooms on a vibrating belt for dirt removal, and removed and replaced mushrooms in Styrofoam packaging containers, as needed, to achieve a desired package weight. Additionally, some packers ran a mushroom slicing machine that sliced white mushrooms and packaged them into bags.

Site 4 manufactured faux stones from concrete. Workers were in charge of concrete mixing and filling of molds. Concrete forms were then painted while in the molds using a variety of spraying and brushing techniques. Once hardened, the stones were pulled manually from the forms and placed into boxes or onto pallets. Pallets of boxed stones were wrapped and placed into trucks for transport.

Study Population

The study population included 162 women and 288 men (N=450 total) (Table 3). Workers were eligible to participate if they performed primarily hand intensive manual (not office) work and were not assigned to more than four tasks. Exclusion criteria included employees who had worked for their current employer less than three months, did not expect to be working for their current employer for at least one year, or spent more than 25% of their time on a forklift or a computer. There were similar numbers of participants under 40 (n=234) and over 40 (n=216) years of age. Over 85% of the participants were Hispanic (n=435). Nearly 35% of the participants had a body mass index (BMI) greater than 30 (n=154). Only 3% (n=14) were left-handed. Approximately 9% of the participants had a medical condition that included diabetes (n=28), lupus (n=1), rheumatoid arthritis (n=11), thyroid disease (n=4) or gout (n=4). Only 15% (n=67) smoked and another 16% reported previously smoking (n=73). Approximately 1% (n=4) had previous physician diagnosed hand or wrist tendinopathy, 3% (n=13) had a history of physician diagnosed carpal tunnel syndrome and 2 individuals reported having a history of physician diagnosed epicondylitis. Overall, 4% (n=19) and 7% (n=31) reported having a previous hand or wrist fracture or strain/sprain injury and 8% (n=24) had an active Workers Compensation Claim. Only 1 woman was pregnant and 6 were taking birth control pills. Approximately 28% of participants (n=122) were on some type of medication including medications for anxiety and depression.

Fifty two percent of participants (n=236) engaged in at least one hour of physical or hand intensive activity per week. About 71% (n=312) felt their health status was good, very good, or excellent. The majority of participants (91%) had some to no high school education and 50% reported making less than $30,000 per year, though the highest percentage of workers by worksite making less than $30,000 per year were concentrated at Site 3 (96%).

Job Characteristics

Sixty-three percent (n=280) of the participants worked the day shift with the remaining participants working swing, rotating or night shifts. Fifty-seven percent (n=256) had worked at their job for more than five years, and nearly 92% (n=396) of participants reported that they were satisfied with their job (Table 3). Thirteen (n=58) and 21% (n= 89)of workers reported being mentally or physically exhausted often or more, and 13% reported being sleepy or fatigued on the job often or more.

High and low categorization of job psychosocial scales including physiological demand, decision latitude, and overall support were calculated based on median splits of the total cohort (Table 4). Physiological demand was high in approximately 44% (n=194) of workers, decision latitude was low in approximately 48% (n=206) of workers, and overall support was low in approximately 49% (n=212) of workers. Overall Job Strain was relatively low in 73% (n=313) of participants and iso-strain was low in approximately 85% if participants. By jobsite, Site 3 had a relatively larger percentage of individuals with high job strain (38%) than the other three sites (18-25%), though iso-strain indices were fairly consistent across sites.

There were a total of 46 different jobs and 144 tasks included in the analysis. Table 5 provides some detail on the types of jobs that participants had, and the tasks they engaged in given their job. The jobs with the largest number of people were at site 4 including General Production Specialists (n=118) and Line 4 Mold Specialists (n=26) who painted and packed concrete stones. At site 3, there were a large number of individuals who picked white mushrooms (n=85), and portabella mushrooms (n=19), and a considerable number who packaged the mushrooms (n=22). At site 2, 12 participants sewed the covers for the chairs and at site 1, there were a considerable number of participants who were machine operators (n=13) and wet order selectors (n=13) who pulled product according to orders to prepare it for transport. Out 413 workers with non-imputed task identification or duration, 99 (24%), had 4 tasks, 130 workers (31%) had 3 tasks, 29 workers (7%) had 2 tasks, and 155 workers (38%) had only one task (Figure 1). A majority of workers (n=378) did their primary task greater or equal to 20 hours per week. Only 72 workers (17%) had their primary task be a duration of less than 20 hours, and approximately 206 workers (50%) primary task was 30 hours per week or longer. Forty of the 144 tasks had more than 5 people performing the same task (Figure 2).

Tables & Figures

Table 1. Outcome measures for wrist diagnoses.

*Core symptoms include: point tenderness, local warmth, redness, localized swelling, and crepitance

Diagnosis	Tests/Symptom Outcome Variables	Diagnosis Criteria
Wrist Flexor Tendinosis		
Flexor Carpi Radialis Tendinosis	• Pain scale • Muscle test of FCR • Core symptoms* over FCR tendon	Positive muscle test **AND** at least one positive core symptom
Flexor Carpi Ulnaris Tendinosis	• Pain scale • Muscle test of FCU • Core symptoms* over FCU tendon	Positive muscle test **AND** at least one positive core symptom
Digital Flexor Tendinosis	• Pain scale • Muscle test of Flexor Digitorum • Core symptoms* over FD tendon	Positive muscle test **AND** at least one positive core symptom
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 Compart. 1 Tendinosis	• Pain scale • Finklestein Test • Hitchikers Sign • Core symptoms* over APL & EPB tendon	Positive Finklestein **OR** positive Hitchikers
Dorsal Compart. 2 Tendinosis	• Pain scale • Muscle test of ECRL & ECRB • Core symptoms* over ECRL & ECRB tendon	Positive muscle test **AND** at least one positive core symptom
Intersection Syndrome	• Pain scale • Point tenderness • Localized swelling • Crepitance	Two of the three possible findings.
Dorsal Compart. 3 Tendinosis	• Pain scale • Muscle test of EPL • Core symptoms* over EPL tendon	Positive muscle test **AND** at least one positive core symptom
Dorsal Compart. 4 Tendinosis	• Pain scale • Muscle test of EDC & EIP • Core symptoms* over EDC & EIP tendon	Positive muscle test **AND** at least one positive core symptom
Dorsal Compart. 5 Tendinosis	• Pain scale • Muscle test of EDM • Core symptoms* over EDM tendon	Positive muscle test **AND** at least one positive core symptom
Dorsal Compart. 6 Tendinosis	• Muscle test of ECU • Core symptoms* over ECU tendon	Positive muscle test **AND** at least one positive core symptom

Table 2: Exposure Variables Measured by Task

Exposure Variables	**Measurement Tool**	**Variable Description**
Force	Self-Report	• Borg CR-10: 0 to 10 (categorical) • Visual Analog Scale (continuous)
	Observer-Rated	• Duration of exertion (0 to 80%)
	Direct Measurement (force matching or force measurement)	• % MVC pinch: 0% to 100% (continuous) • % MVC Grip: 0% to 100% (continuous) • Normalized peak Force (MVC normalized to a 0 to 10 scale) • Peak Hand Force • Tool Weight
	Video Analysis	• % time in: no load, light pinch, heavy pinch, light grip, heavy grip, any pinch, any grip, any heavy hand posture, any light hand posture, and all (heavy & light) hand postures (continuous)
Repetition	Observer-Rated	• Hand activity level: 0 to 10 scale (categorical) • Speed of work: very slow, slow, fair, fast, very fast (categorical) • Efforts per min: 1 to 20/minute (continuous)
	Video Analysis	• # reps/minute: no load, light pinch, heavy pinch, light grip, heavy grip, any pinch, any grip, any heavy hand posture, any light hand posture, and all five hand postures (continuous)
Posture	Observer-Rated	• Wrist Posture: very good, good, fair, bad, very bad (categorical)
Composite Scales		
ACGIH HAL TLV: to assess combination of repetition and force	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 hand posture (grip or pinch)	• Ratio: between 0 and 1 (continuous)
Moore-Garg Strain Index: to assess combination of posture, repetition, and force	Force: Direct Measure Repetition & Posture: Observer Rated	• Strain Index value: >0 (continuous)

Table 3: Participant demographics.

Participant Demographics	Site 1			Site 2			Site 3			Site 4			Total		
	n=55			n=35			n=171			n=189			n=450		
	n	N	%	n	N	%	n	N	%	n	N	%	n	N	%
Gender															
Male	49	55	89%	19	35	54%	73	171	43%	147	189	78%	288	450	64%
Female	6	55	11%	16	35	46%	98	171	57%	42	189	22%	162	450	36%
Age (years)															
<20 years of age	0	55	0%	1	35	3%	1	171	1%	3	189	2%	5	450	1%
20 to 29 years	20	55	36%	5	35	14%	44	171	26%	43	189	23%	112	450	25%
30 to 39 years	16	55	29%	5	35	14%	51	171	30%	45	189	24%	117	450	26%
40 to 49 years	19	55	35%	14	35	40%	39	171	23%	67	189	35%	139	450	31%
50 to 59 years	0	55	0%	8	35	23%	25	171	15%	27	189	14%	60	450	13%
> =60 years	0	55	0%	2	35	6%	11	171	6%	4	189	2%	17	450	4%
Ethnicity															
Native American	1	55	2%	3	32	9%	0	163	0%	0	185	0%	4	435	1%
Asian or Pacific Islander	0	55	0%	1	32	3%	3	163	2%	2	185	1%	6	435	1%
African American	4	55	7%	0	32	0%	0	163	0%	3	185	2%	7	435	2%
Hispanic	26	55	47%	15	32	47%	155	163	95%	177	185	96%	373	435	86%
White	20	55	36%	11	32	34%	4	163	2%	2	185	1%	37	435	9%
Body Mass Index															
<30	31	49	63%	24	33	73%	125	170	74%	108	189	57%	288	441	65%
>30 (obese)	18	49	37%	9	33	27%	45	170	26%	81	189	43%	154	441	35%
Medical History															
No Medical Condition	48	51	94%	29	34	85%	159	170	94%	167	189	88%	403	444	91%
Medical Condition	3	51	6%	5	34	15%	11	170	6%	22	189	12%	41	450	9%
Gout	0	50	0%	0	33	0%	0	170	0%	4	188	2%	4	441	1%
Rheumatoid Arthritis	2	51	4%	0	33	0%	3	170	2%	6	187	3%	11	441	2%
Lupus Erythmatodes	0	50	0%	0	33	0%	0	170	0%	1	187	1%	1	440	0%
Hyper/Hypothyroidism	0	50	0%	1	33	3%	1	170	1%	2	188	1%	4	441	1%
Diabetes	1	50	2%	4	34	12%	7	170	4%	16	189	8%	28	443	6%
Pregnant	0	6	0%	0	16	0%	1	98	1%	0	42	0%	1	162	1%
Birth Control Pill	0	6	%	0	16	0%	3	98	3%	3	42	7%	6	162	4%
Taking Medication	14	52	27%	12	32	38%	59	168	35%	37	182	20%	122	434	28%
Antidepressant medication	2	23	9%	2	20	10%	3	101	3%	1	19	5%	8	163	5%
Thyroid Medication	1	23	4%	0	19	0%	2	100	2%	2	18	11%	5	160	3%
Diabetes Medication	1	23	4%	2	21	10%	9	100	9%	10	24	42%	22	168	13%
Anxiety/ Sleeping Pills	1	23	4%	1	19	5%	0	100	0%	0	18	0%	2	160	1%
Previous Neck/Upper Extremity Injury	17	55	31%	7	34	21%	22	168	13%	31	186	17%	77	443	17%
Previous Hand/Wrist Tendonitis	2	55	4%	1	34	3%	0	168	0%	1	186	1%	4	443	1%
Previous Carpal	1	55	2%	0	34	0%	10	168	6%	2	186	1%	13	443	3%

Tunnel Syndrome															
Previous Epicondylitis	1	55	2%	0	34	0%	0	168	0%	1	186	1%	2	443	0%
Previous Upper Extremity Fracture	8	55	15%	2	34	6%	2	168	1%	7	186	4%	19	443	4%
Previous Strain/Sprain	2	55	4%	2	34	6%	8	168	5%	19	186	10%	31	443	7%
Current Workers Compensation Claim	8	41	20%	0	24	0%	11	96	11%	5	123	4%	24	284	8%
Smoking Status															
Never smoked	32	54	59%	14	34	41%	129	169	76%	130	189	69%	305	446	68%
Previously smoked	9	54	17%	10	34	29%	19	169	11%	35	189	19%	73	446	16%
Currently Smokes	13	54	24%	10	34	29%	21	169	12%	23	189	12%	67	446	15%
Weekly Activity															
Weekly Exercise (any weekly activity >=1hour)	30	55	55%	20	35	57%	80	171	47%	106	189	56%	236	450	52%
Walking	0	55	0%	3	35	9%	4	171	2%	17	189	9%	24	450	5%
Running	1	55	2%	0	35	0%	1	171	1%	11	189	6%	13	450	3%
Swimming	1	55	2%	1	35	3%	0	171	0%	2	189	1%	4	450	1%
Biking	1	55	2%	1	35	3%	0	171	0%	2	189	1%	4	450	1%
Baseball/softball	3	55	5%	3	35	9%	0	171	0%	4	189	2%	10	450	2%
Basketball	3	55	5%	3	35	9%	0	171	0%	5	189	3%	11	450	2%
Soccer	0	55	0%	0	35	0%	0	171	0%	9	189	5%	9	450	2%
Volleyball	0	55	0%	0	35	0%	1	171	1%	3	189	2%	4	450	1%
Football	1	55	2%	0	35	0%	2	171	1%	20	189	11%	23	450	5%
Weightlifting	12	55	22%	0	35	0%	4	171	2%	2	189	1%	18	450	4%
Gardening	6	55	11%	2	35	6%	5	171	3%	16	189	8%	29	450	6%
Computer/video games	1	55	2%	0	35	0%	0	171	0%	2	189	1%	3	450	1%
Musical Instrument	1	55	2%	0	35	0%	0	171	0%	3	189	2%	4	450	1%
Home Repair	3	55	5%	1	35	3%	1	171	1%	3	189	2%	8	450	2%
Cleaning, cooking, childcare	7	55	13%	10	35	29%	68	171	40%	24	189	13%	109	450	24%
Overall Health Status															
Poor	2	54	4%	1	34	3%	4	164	2%	2	184	1%	9	436	2%
Fair	11	54	20%	8	34	24%	54	164	33%	42	184	23%	115	436	26%
Good	26	54	48%	15	34	44%	79	164	48%	93	184	51%	213	436	49%
Very Good	11	54	20%	7	34	21%	25	164	15%	33	184	18%	76	436	17%
Excellent	4	54	7%	3	34	9%	2	164	1%	14	184	8%	23	436	5%
Current Shift															
Day Shift	17	54	31%	26	29	90%	164	170	96%	73	188	39%	280	441	63%
Swing Shift	17	54	31%	3	29	10%	6	170	4%	65	188	35%	91	441	21%
Night Shift	13	54	24%	0	29	0%	0	170	0%	48	188	26%	61	441	14%
Rotating/Irregular Shift	7	54	13%	0	29	0%	0	170	0%	2	188	1%	9	441	2%
Educational Level															
8th grade or less	0	55	0%	4	32	13%	112	166	67%	91	189	48%	207	442	47%
Some HighSchool/ graduate	35	55	64%	19	32	59%	52	166	31%	88	189	47%	194	442	44%
Some College/ graduate	20	55	36%	9	32	28%	2	166	1%	10	189	5%	41	442	9%
Annual Income															
< $30,000 per	8	38	21%	8	19	42%	72	75	96%	66	174	38%	154	306	50%

year															
>= $30,000 per year	30	38	79%	11	19	58%	3	75	4%	108	174	62%	152	306	50%
Years at Job															
<2 years	13	55	24%	12	35	34%	21	171	12%	52	189	28%	98	450	22%
>=2 years & < 5 Years	11	55	20%	12	35	34%	28	171	16%	45	189	24%	96	450	21%
> 5 years	31	55	56%	11	35	31%	122	171	71%	92	189	49%	256	450	57%
Job Satisfaction															
Poor or Fair	7	54	13%	2	32	6%	12	160	8%	14	185	8%	35	431	8%
Good or Excellent	47	54	87%	30	32	94%	148	160	93%	171	185	92%	396	431	92%
Mentally Exhausted															
Never or some of the time	37	53	70%	24	31	77%	144	162	89%	168	185	91%	373	431	87%
Often or Always	16	53	30%	7	31	23%	18	162	11%	17	185	9%	58	431	13%
Physically Exhausted															
Never or some of the time	31	54	57%	17	30	57%	144	163	88%	151	185	82%	343	432	79%
Often or Always	23	54	43%	13	30	43%	19	163	12%	34	185	18%	89	432	21%
Sleepy on the Job															
Never or some of the time	44	55	80%	21	32	66%	150	163	92%	162	184	88%	377	434	87%
Often or Always	11	55	20%	11	32	34%	13	163	8%	22	184	12%	57	434	13%

Table 4: Work psychosocial characteristics by site.

Job Psychosocial Characteristics by Site	Site 1			Site 2			Site 3			Site 4			Site 5		
	n=55			n=35			n=171			n=189			n=450		
	n	**N**	**%**	**n**	**N**	**%**	**n**	**N**	**%**	**n**	**N**	**%**	**n**	**N**	**%**
Job Psychosocial Scales															
Physiological Demand															
Low	22	55	40%	15	32	47%	117	166	70%	90	185	49%	244	438	56%
High	33	55	60%	17	32	53%	49	166	30%	95	185	51%	194	438	44%
Decision Lattitude															
Low	21	55	38%	15	30	50%	69	163	42%	101	182	55%	206	430	48%
High	34	55	62%	15	30	50%	94	163	58%	81	182	45%	224	430	52%
Skill Discretion															
Low	13	55	24%	11	32	34%	50	166	30%	106	185	57%	180	438	41%
High	42	55	76%	21	32	66%	116	166	70%	79	185	43%	258	438	59%
Decision Authority															
Low	28	55	51%	14	30	47%	66	163	40%	63	182	35%	171	430	40%
High	27	55	49%	16	30	53%	97	163	60%	119	182	65%	259	430	60%
Overall Support															
Low	27	55	49%	16	30	53%	86	164	52%	83	185	45%	212	434	49%
High	28	55	51%	14	30	47%	78	164	48%	102	185	55%	222	434	51%
Supervisor Support															
Low	17	55	31%	14	30	47%	59	164	36%	71	185	38%	161	434	37%
High	38	55	69%	16	30	53%	105	164	64%	114	185	62%	273	434	63%
Co Worker Support															
Low	10	55	18%	2	31	6%	5	165	3%	13	186	7%	30	437	7%
High	45	55	82%	29	31	94%	160	165	97%	173	186	93%	407	437	93%
Job Psychosocial Indices															
Job Strain															
Low	41	55	75%	23	30	77%	100	162	62%	149	182	82%	313	429	73%
High	14	55	25%	7	30	23%	62	162	38%	33	182	18%	116	429	27%
Iso Strain															
Low	46	55	84%	25	30	83%	131	160	82%	160	182	88%	362	427	85%
High	9	55	16%	5	30	17%	29	160	18%	22	182	12%	65	427	15%

Table 5: Job and task summary by site.

	Task Title	N		Task Title	N
SITE 1			**SITE 1**	**(cont)**	
JOB #1	Pasteurizer	4	**JOB #15**	**Blowmold Machine Op**	1
1	Computer Monitoring	4	**56**	Machine Tending	1
2	Clean in Place	3	**184**	Pick up Plastic Bottles	1
3	Sample Product	4	**185**	dump/lift boxes overhead	1
4	Wrenching	4	**JOB #16**	**Hand Packer**	1
JOB #2	Machine Operator	13	**57**	Hand pack 5lb tubs into cases	1
5	Operate Juice Filler	4	**58**	Running Buckets	1
6	CIP	11	**JOB #17**	**Ship/Receive**	2
7	Change Over	8	**59**	Hand Pack into Box	2
8	Operate Milk Filler	2	**60**	Tend Machine	1
9	Operate Filler Bags	1	**JOB #18**	**CIP**	2
10	Sampling	1	**64**	Bending/Lifting	1
167	Operate Ice Cream Machine	2	**65**	Hand scrubbing tanks	1
168	CIP Ice Cream Machine	1	**66**	Sweeping/ Mopping floors	1
JOB #3	**Dockman**	2	**67**	Quilling Product	1
11	Unload Empty Crates	2	**JOB #19**	**Cream Cheese Packer**	3
12	Wash Trailers	2	**68**	Machine Packing	3
13	Stack Pallets	2	**69**	Hand Packing	3
JOB #4	**Racker**	4	**70**	Hand Palletizing	2
15	Lift/Lower Empty Crates	3	**SITE 2**		
16	Hand Rack Milk into Stacks	4	**JOB #20**	**Cutter**	3
17	Pull Milk Stacks	3	**71**	Material Preparation	3
JOB #5	**Inventory Specialist**	1	**JOB #21**	**Upholstery**	3
18	Unloading/Loading Trucks	1	**74**	Install Chair Tacks	1
20	Put Stock Away	1	**75**	Upholster Backs	1
170	Inventory Product	1	**171**	Assembling Arm Upholster	1
JOB #6	**Order Selector-Wet**	13	**172**	Assembly Station	1
21	Pull Stack of Products	12	**173**	Upholster Chairs	1
22	Pick Orders	13	**JOB #22**	**Foam**	3
23	Check Orders	11	**76**	Apply Steam	1
169	Load Trucks	7	**77**	Glue material to wood	2
JOB #8	**Lab Tech**	1	**78**	Load product onto rack	1
29	Routine Plating	1	**174**	prepare foam for upholstery	1
30	Pipetting	1	**JOB #23**	**Sewer**	12
31	Sample Shaking	1	**79**	sews material	12
JOB #11	**Corrugated Operator**	4	**80**	prep/cut foam/dacron	2
38	Load Boxes	3	**JOB #24**	**Shipping**	4
39	Fiz Palletizers	3	**81**	chair base assembly	1
40	Tend machines	3	**82**	make box	2
41	CIP	3	**175**	prepare chairs for shipping	2
JOB #13	**Cheesemaker**	2	**JOB #25**	**Assembly- Executive**	2
49	Run Cheese Vat	1	**84**	assemble chairs	1
50	Clean Cheese Vat	1	**85**	assemble chair seats	1
51	Lift 50lb bags	1	**JOB #26**	**Assembly- Task**	8
JOB #14	**Churn Operator**	2	**86**	assemble chair mechanism	1
52	Stack Butter	1	**87**	assemble chair seats	1
53	Paddle Butter	1	**88**	assemble seat backs	1
54	Stack Pallets & Bags	1	**89**	stringer	2
			90	assemble tcks	1

91	assemble couch	1

	Task Title	N
SITE 3		
JOB #27	**Picker- White**	85
92	Picking Mushrooms	81
JOB #28	**Picker- Portabella**	19
93	Picking Mushrooms	17
JOB #32	**Grower/Inspector**	8
107	Check for mummies	7
180	wat mushroom beds	2
186	wash floors	1
JOB #33	**Washer**	4
108	load baskets into tubs	4
109	clean totes	4
JOB #34	**Packing**	6
113	palletize mushrooms into boxes	1
JOB #35	**Bulkline Packer**	9
114	Fill boxes with sliced mushrooms	6
115	pour sliced mushrooms into boxes	7
116	weigh	5
117	Stack/ Palletize	8
118	Stamp date onto boxes	1
177	Load Conveyor with boxed mushrooms	1
JOB #36	**Line Packer**	22
119	Weigh Mushroom	12
120	remove/add mushrooms	6
121	palletize mushrooms into boxes	3
123	erect cardboard carton	4
176	sort baskets on conveyor	1
195	CIP	1
JOB #38	**Slice Packer**	5
124	load empties into machine	3
125	pour mushrooms	7
126	palletize mushrooms	4
JOB #39	**Bag Line Packer**	1
127	Hand pack bagged mushrooms	1
JOB #40	**Portabella Packer**	5
128	fill tills with mushrooms	2
129	Transfer portbella to tray	2
130	palletize	1
JOB #50	**Tray Repair**	3
178	shovel/ move trays	1
179	repair mushroom beds	1
JOB #51	**Sweeper**	3
181	sweep floors	3
182	remove trash	3

	Task Title	N
SITE 4		
JOB #41	**General Production Specialist**	118
131	Paint	57
132	Pack Stones	52
133	Pull from molds	53
135	pour	13
136	stack pallets/ molds	3
JOB #42	**Line 2 Production Specialist**	12
137	paint	12
138	pull&pack	9
140	smooth/ pour/ scrape	7
141	pull	13
194	smoothing	2
197	color coordinate	1
JOB #43	**Line 4 Mold Specialist**	26
143	dabbing	23
144	spraying	24
145	pasting	24
JOB #44	**Color Coordinator**	5
149	paint	1
152	paint & carry heavy items	1
JOB #45	**Quality Control**	6
153	stock molds	1
154	inspect molds	2
193	revise concrete	1
JOB #47	**Batchman**	7
158	mix cement	2
JOB #48	**Production Excalibur**	5
162	dump molds	1
163	stack molds	1
164	pack flat stones	1
JOB #49	**Mold Analyst**	1
JOB #52	**SPS**	3
183	run a line	1
JOB #53	**Janitor**	1
187	janitorial	1
JOB #54	**Line 4 Production Specialist**	2
188	fiberglass work	1
189	corners	2
190	foam	2
191	Table Assembly	2
192	pulling	1

FIGURE 1: Number of tasks per worker.

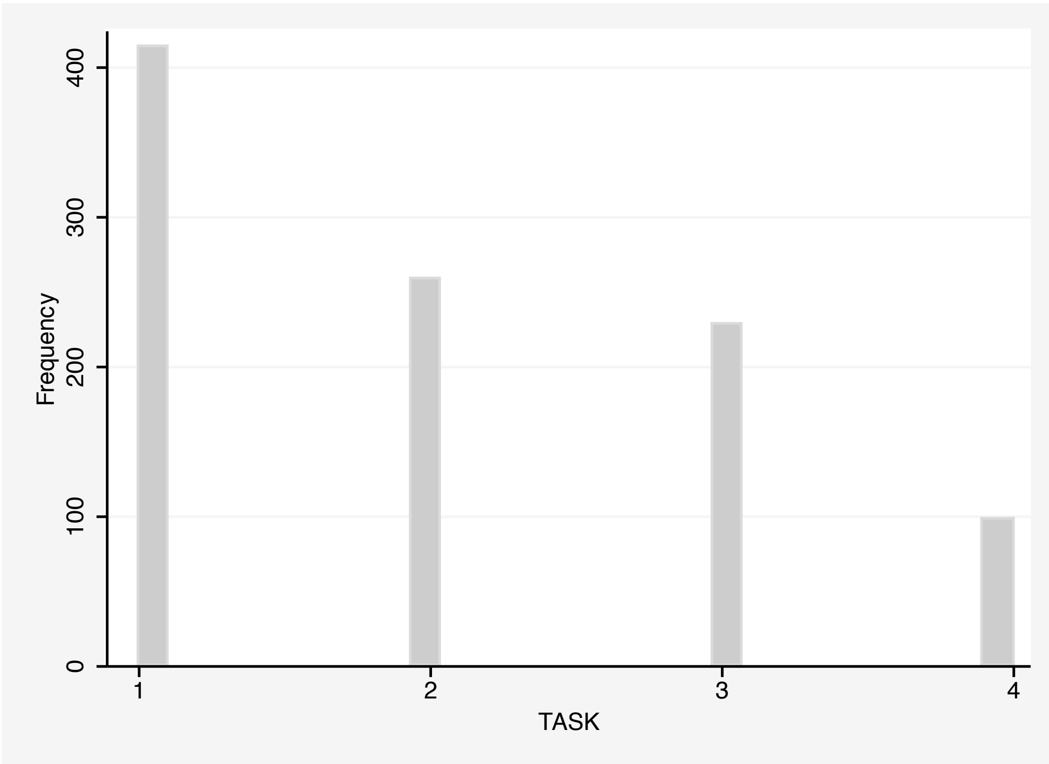
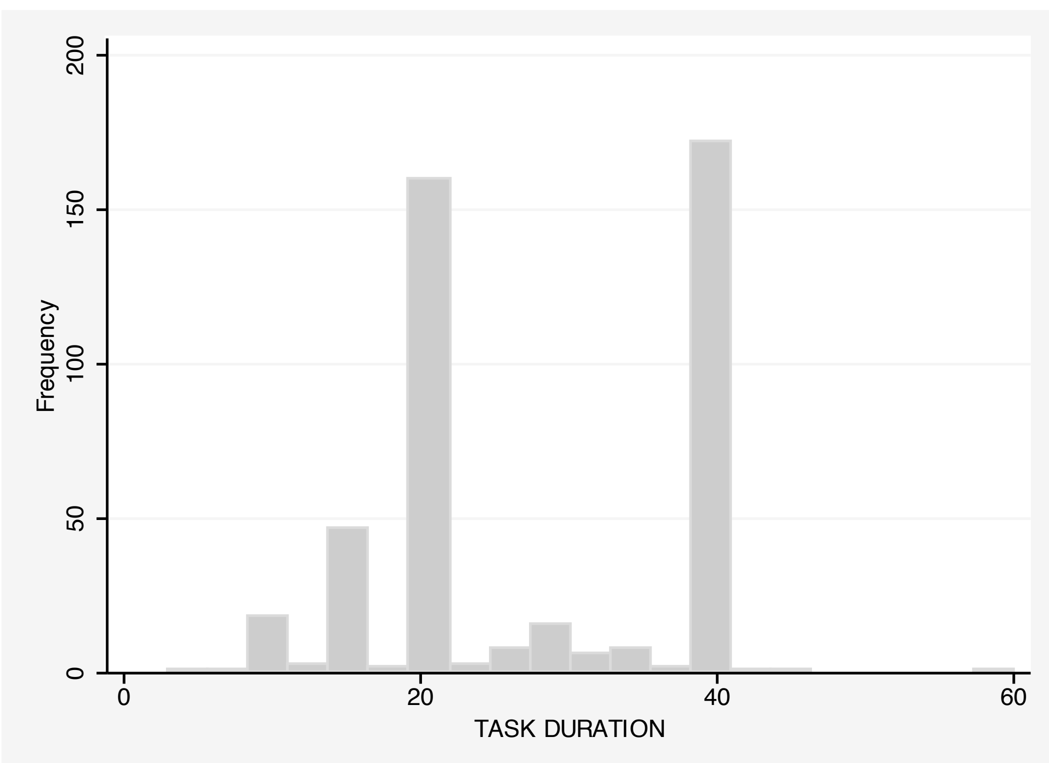


FIGURE 2: Number of hours for task of highest duration.



Exposure Variable Analysis

Introduction

Force and repetition are the two important risk factors for tendinosis in the hand or wrist. Each of these risk factors individually places workers at an increased risk for developing a distal upper extremity disorder, and when combined at high levels, the risk of injury increases more than just the sum of the two (Silverstein et al, 1987). Methods used to quantify a worker's exposure to force and repetition varies on many levels. For example, the type of data collected varies between self-report scales, observer-rated categorization on scales, and direct measurement of force in the field or from analysis of videotapes.

To quantify force, workers may provide an assessment of their exertion using the 0 to 10 rate of perceived exertion scale (RPE) or their hand fatigue by placing a mark on a 10 cm line (VAS) to indicate how fatigued they feel after completing a certain task. Additionally, a trained observer may assess a worker completing a task and use physical cues, such as "no visible signs of fatigue", to rate the exertion level of the worker performing a certain task. A trained observer can also quantify the force by direct measurement of hand tools used, peak force measurement, or force matching. The weight of a hand tool is correlated with the amount of grip force required to use the tool (Bao et al., 2006). However, the relationship between tool weight and force can diverge for small or light tools since a high pinch can easily be required to utilize even the lightest of tools, depending on how the tool is used. For example, a dental scaling tool may require very little force to hold, yet when it is used to scrape a tooth may require high pinch force. Another direct method for quantifying force is to measure it with a force gage. However, depending on the application, this method can be challenging and likely has different levels of reliability and accuracy. For example, when quantifying the amount of force to pull a cart, it can be simple to connect a force gage to the cart and measure the amount of pull force required to move it, however, it can be challenging to measure the actual grip force associated with the activity especially if the cart is turned while pushing. A third direct measurement method often used to quantify grip and pinch forces, is force matching. Force matching involves positioning a grip or pinch dynamometer so that the arm and hand are close to the position of actual grip or pinch and asking the worker to do their task, then mimic the grip involved in the task on the force or pinch gage. Usually, 3-5 trials are done and the worker is blinded to the results of each trial. The accuracy of this method is limited (Bao & Silverstein, 2005).

Another way to quantify force is to use a meaningful force threshold and categorize the amount of time the hand is gripping above the threshold. This method was used in this study by analyzing the videotape of the worker's hands on a frame-by-frame basis, then calculate the percent of time spent in heavy or light pinch or grip. The advantage of this method is that it very accurately records the amount of time (or duty cycle) that the hand is applying no, low or high forces, but does not produce exact force measurements. The validity of the thresholds selected was based on previous research, for example, indicating that a threshold of 1kg and 4kg of pinch and grip force was shown to increase the risk of developing a DUE (Silverstein et al., 1986). Direct measurement methods, such as force matching or tool weight, can be used to compliment this method of categorizing the time spent in a heavy or light pinch or grip. This method of video analysis involves extensive evaluator time to analyze the videos. If this technique has value in identifying workers at risk for a DUE, then a more practical method for applying this technique could be developed.

Repetition is another risk factor for the development of DUE and it can also be quantified in various ways including, self-report, observer-rated, and direct measurement.

Method of Statistical Analysis

Summary Measures of Exposure Variables

Force. Force measurements included those from self-report, observer-rated, direct measurement, and video motion analysis procedures (Table 1). Self-report measures of force included the task specific rate of perceived exertion (RPE) and the task and side specific visual analog scale (VAS). Observer-rated measure of force included the duration of exertion from 0 to 80% and was a percentage of time a force was applied in a given cycle of a task.

Direct measures of force included measured matching power grip and pinch forces and each as a percent of a workers maximum voluntary contraction (MVC). The percent MVC was calculated by dividing the average of three force matching measurements for position-specific peak pinch/grip (Bao & Silverstein, 2005) by the individuals, or gender specific, maximum contraction norms in the position of use. Hand tool weight was measured via a force gage. The peak grip force was the highest force exerted by the hand and could have included grip, using the hand as a hammer, or exerting a push or pull.

Approximately ten minutes of video were recorded of each task for each subject. The videos were analyzed frame by frame for each hand using Multi Video Task Analysis (MVTA) (Yen, 1995). During the video analyses, the force measurements collected in the field were used to categorize the hand posture for each frame as being engaged in no load (fingers or palm in no contact with any objects), light pinch(<=1kg), significant pinch(>1kg), light grip(<=4kg), and significant grip(>4kg) (Bao et al., 2006). A pinch was defined as a load that was primarily located on the fingers, unevenly distributed between the palm and the fingertips, or a pseudo-power grip (a grip around a thin object). A grip was defined as a load that was evenly distributed between the palm and the fingertips or primarily located on the palm. The percent time that the hand was in each posture was calculated by summing its number of frames and dividing it by the total number of frames observed for that task. The percent time spent in all force pinch and grip postures was the sum of the percent time spent in light pinch, heavy pinch, light grip, and heavy grip. Other summation values included the percent time spent in any pinch (heavy and light), any grip (heavy and light), any heavy hand posture (pinch and grip), and any light hand posture (pinch and grip).

Repetition. Observer-rated repetition measurements included the HAL scale rating (0 to 10 scale) with 6 anchors that varied between 'hands being idle most of the time' to 'rapid steady, motions, difficulty keeping up' (Table 1). The speed of work rating (0 to 5 scale) rated the speed of activity from 'very slow' to 'very fast'. The efforts-per-minute (0 to 20 scale) was an observer rated measure that counted exertions while observing a worker perform a task. Video analysis provided the repetition rate for five hand postures, and their summations. The number of wrist exertions in each hand posture provided a total and posture specific repetition rate (reps/min) for each video analyzed. The definition of an exertion was either a forceful movement of the wrist or fingers, (wrist extension/flexion, finger extension/flexion) or a change in the defined load of the hand or fingertips. Total repetitions per minute was the sum of exertions in all five hand postures including no load, light pinch, heavy pinch, light grip, and heavy grip. Other summation values include the repetition rate per minute in any pinch (heavy and light), any grip (heavy and light), any heavy hand posture (pinch and grip), and any light hand posture (pinch and grip). If the hand was not visible in a frame, the posture was allocated to a 'no data' category and not included in the overall assessment of percent time or number of exertions in different hand postures.

Associations Among Exposure Variables

The associations between data collected using the different ways of measuring force and repetition were analyzed. Self-report measures of force included the rate of perceived exertion and the visual analog scale. Direct measures of force included tool weight, the peak grip force, matching grip force, and matching pinch force. Video analysis measures of force included the percent time spent in no load, any pinch, light pinch, heavy pinch, any grip, light grip, heavy grip, heavy pinch or grip, light pinch or grip and all grip and pinch. Self-report measures of repetition included the HAL Scale as a summary measure across all tasks. Observer rated measures included the HAL Scale, efforts per minute, and speed of work for each task. Video analysis measures of repetition included the number of repetitions per minute when in no load, any pinch, light pinch, heavy pinch, any grip, light grip, heavy grip, heavy pinch or grip, light pinch or grip, and all grip and pinch. Most of the data were available at the person-task level.

Pearson correlation coefficients were estimated between measures of force and repetition for one task per subject. The task selected was the one with the largest number of hours per week. Correlations between force measures or repetition measures were analyzed by the type of measure including self-report, observer-rated, direct measure, and video analysis. Further analysis examined the differences between RPE & VAS ratings as a function of force and repetition using correlations, absolute differences, and linear regression within tasks.

Results

Descriptive Summary of Exposure Variables

Summary measures of the exposure variables are the based on time weighted average values of each participant's exposure to each of their tasks (Table 1). Self-report measures of exposure to force included an all task RPE, task specific RPE, and the visual analog scale (VAS). The mean RPE, when asked as a summary of all tasks, was 4.54 (SD=2.24) on a 0 to 10 scale. When asked to rate their perceived exertion on a task-by-task basis the time weighted average value was a mean of 3.3 (SD=1.8). The visual analog scale measuring hand fatigue had a mean of 3.7 (SD=1.8) on a 0 to 10 scale.

The only measure of force that was observer-rated was the duration of exertion measured as a percent of cycle, which was an average of 24.5% (SD= 15.7%). Direct measures of force included tool weight, for tools used by the right hand, which was a mean of 1.9kg (SD=3.1), peak force in any position which was 3.9kg (SD=4.2) of force, force matching in power grip which had an average of 5.9kg (SD=3.27), and force matching in pinch grip which had an average of 1.68kg (SD=2.45). Using force matching, the mean maximum voluntary contraction was 33.8% (SD=14%) and 13.3% (SD=10.6%) while gripping and pinching. Overall, video analysis indicated that participants spent an average of 65.5% (SD=15%) of their time in any grip or pinch while working and 18% (SD=14%) of their time in no hand load at all. The percent time spent in pinch (50.8%, SD=17.2%) can be further described as 27.8% (SD=18.5) of time in light pinch and 23.2% (SD=17%) in heavy pinch. The percent time spent in heavy grip can be further described by 9% (SD=9.7%) in light grip and 6.3% (SD=8.9%) in heavy grip. On average, 29% (SD=19.5%) of participants' time was spent in either heavy pinch or grip.

The self-reported measure of repetition using the HAL Scale during baseline assessment was based on a summary of all tasks performed and was an average of 3.83 (SD=0.92). Observer-rated measures included a task specific HAL Scale with a mean of 4.9 (SD=2.2) out of 10, and a mean speed of activity rating of 3.3 (SD=1) out of 5.

From the video analysis participants spent an average of 50.7 reps/min (SD=24.1) while in no load, gripping or pinching. They spent 9.0 reps/min (SD=7.7) while in no load. The repetition rate while in pinch was 17.1 reps/min (SD=15) and 16.1 reps/min (SD=16.8) while in light and heavy pinch, respectively. The repetition rate in heavy grip was an average of 3.7 reps/min (SD=4.3) while in light grip and 5.3reps/min (SD=12.8) while in heavy grip. The average repetition rate while in either heavy pinch or grip was 21.1reps/min (SD=23.4).

Associations between Measures of Force

Self-Report Measures*.* Correlation values were based on the task of highest duration for each subject. Two self-report measures of force, the task specific RPE and the VAS, had a strong correlation (*r*=0.63) (Table 2). The task specific RPE had a moderate correlation with the percent time spent in heavy pinch (*r*=0.41) and heavy pinch and grip (*r*=0.35). The VAS had a moderate correlation with the percent time in heavy pinch (*r*=0.35) and similar yet weaker correlations in percent time in any pinch (*r*=0.19) and heavy grip and pinch (*r*=0.27).

Direct Measures. Tool weight showed moderate correlations with peak grip force (*r*=0.37), matching grip force (*r*=0.46), and matching pinch force (*r*=0.38) (Table 2). Peak grip force was negatively correlated with percent time in heavy or light pinch (*r*=-0.42) and positively correlated with percent time in heavy or light grip(*r*=0.45).

Video Analysis Measures. The percent time spent in no load had a negative moderate correlation with the percent time spent in all other hand postures (Table 2), and was positively correlated with tool weight (*r*=0.38), and normalized peak force (*r*=0.29). The percent time in light pinch was negatively correlated with all other postures including the percent time in heavy pinch(*r*=-0.3), light grip(*r*=-0.35), and heavy grip(r=-0.39), as well as the percent time in any grip (*r*=-0.51). The percent time spent in heavy pinch was negatively correlated with both the percent time spent in any grip (*r*=-0.42). The percent time in light grip and in heavy grip were not correlated (*r*=0.05).

Associations between Measures of Repetition

Self-Report Measures. The self-reported HAL Scale at baseline based on all tasks had a very low correlation with the task specific observer-rated HAL Scale (*r*=0.05) and speed of work (*r*=0.13), yet a weak moderate correlation with the observer-rated task specific number of efforts per minute (*r*=0.29) (Table 3).

Observer-Rated Measures. Observer-rated task specific measure of the HAL scale had a strong correlation with speed of work (*r*=0.65) and a weaker correlation with efforts per minute (*r*=0.21) (Table 3). The HAL Scale had weak correlations with each individual measure of repetition from the video analysis, except the percent time spent in power grip (*r*=0.47), and therefore any grip (*r*=0.41). The speed of work rating had negative correlations with the repetition rate while in heavy pinch (*r*=-0.27) and light grip (*r*=-0.28) and a moderate correlation with heavy grip (*r*=0.37).

Video Analysis Measures. The repetition rate while in no load had low to weak moderate correlations with all other video analysis measures that were independent of it. The repetition rate while in light pinch had weak moderate negative correlations with the repetition rate while in heavy pinch (*r*=-0.22), light grip (*r*=-0.17), and heavy grip (*r*=-0.19). The repetition rate while in heavy pinch had very low correlations with the repetition rate while in light grip (*r*=0.03) and heavy grip (*r*=0.00). The repetition rate while in light grip and heavy grip had low correlations with all other video based measures of repetition.

Associations between Measures of Force & Repetition

Self-Report Measures*.* The self-reported all task measure of repetition (HAL Scale) had a weak moderate correlation (*r*=0.25) with the all task measure of RPE at baseline, and a very low correlation with RPE (*r*=0.01) and VAS (*r*=-0.01) by task (Table 4).

Observer-Rated & Direct Measures. The observer-rated HAL Scale by task had a weak moderate negative correlation with tool weight (*r*=-0.25), and a moderate positive correlation with matching pinch force (*r*=0.42) (Table 5). The observer-rated efforts per minute had a moderate negative correlation with tool weight (r=-0.36), moderate correlations with peak grip force (*r*=0.38) and matching grip force (*r*=0.35), and a low correlation with normalized peak force (*r*=0.12). The speed of work had a moderate negative correlation with tool weight (*r*=-0.45) and low correlations with all other direct measures of force.

Video Analysis Measures. The percent time spent in no load had a strong positive correlation with the repetition rate in no load (*r*=0.56), and negative low to moderate correlations with repetition rates in all other grip postures (Table 6). The percent time spent in light pinch had a strong correlation with the repetition rate in light pinch (*r*=0.87), and negative moderate correlations with repetition rates in other core hand postures. The percent time spent in heavy pinch had a strong correlation with the repetition rate in heavy pinch (*r*=0.87) and all grip or pinch (*r*=0.48), and a moderate negative correlation with the repetition rate in light pinch (*r*=-0.28) and all grip (*r*=-0.2). The percent time in other core hand posture measures had similar patterns with moderate to strong correlations with the repetition rate during their same hand posture, and negative correlations with the repetition rate in other core hand postures. The percent time spent in any pinch had strong correlations with the repetition rates in any pinch (*r*=0.78), light pinch (*r*=0.55), heavy pinch (*r*=0.45), and all grip and pinch (*r*=0.42), and moderate negative correlations with the repetition rate in any grip(r=-0.48), light grip(r=-0.3), and heavy grip (*r*=-0.41). The percent time in any grip showed a similar pattern. The percent time spent in all grip and pinch postures had a moderate to strong positive correlation with the repetition rate in all grip and pinch (*r*=0.39), any pinch (*r*=0.46), and heavy pinch or grip (*r*=0.36), and a strong negative correlation with the repetition rate in no load (*r*=-0.56).

Analysis between Self-Report Measures of Force: VAS & RPE

The strongest correlation of interest was between the self-reported task-specific measures of the visual analog scale for hand fatigue and the rate of perceived exertion of the hands. The average difference between these measures (n=255) was -0.5 (SD=1.6) and the range of differences was -8.9 to 4.16 (Figure 1). When the absolute difference between measures was analyzed, the mean difference was 1.15 (SD=1.22) and the range of differences was 0 to 8.93 (Figure 2). Weak moderate positive correlations (Table 7) were found between the absolute difference of the VAS and RPE scales and force measures including the percent time in light pinch (r=0.24) and any pinch (r=0.21). Weak moderate negative correlations were found between the absolute difference of the VAS and RPE scales and force measures including the percent time in heavy pinch and grip (r=-0.2) and any grip(r=-0.19), tool weight (r=-0.21), and peak grip force (r=-0.18). Additional moderate negative correlations were found with repetition measures including the HAL scale by task (r=-0.27) and the repetition rate while in light grip (r=-0.24) and any grip (r=-0.2). When assessing these same relationships using linear regression, the percent time in light pinch ($p<0.08$) and the repetition rate in light pinch ($p<0.09$) had strong positive associations, and the observer-rated HAL Scale ($p<0.00$) and repetition rate in light grip ($p<0.08$) had strong negative associations with the absolute difference between self-report VAS and RPE ratings (Table 7). The correlation between the VAS and RPE scales were analyzed within task and a large variation of values was observed (Table 13) ranging between r=-0.89 and r=0.98. The range of absolute differences between the scales and within a task also varied considerably ranging from 0.29 and 2.58. When exposure characteristics within each task were analyzed (Table 8), absolute differences between the RPE and VAS scales greater than one tended to be tasks that had more time spent in light pinch (42%) and less time spent in heavy pinch (17%) or heavy pinch and grip (30%). Alternatively, for tasks with absolute differences between the VAS and RPE scales less than one, the tasks had more time devoted to high pinch (38%) activities and less time in light pinch (12%) activities.

Discussion

Force and repetition are moderately associated with distal upper extremity disorders. It is important to understand the differences between the various methods for quantifying a workers exposure to force and repetition in order to provide effective measures for predicting risk and evaluating interventions for prevention. Exposure measures that quantify the same aspect of an exposure can be used concurrently to validate one another, or in place of one another based on whichever method is easier to utilize in the field. For measures that quantify different aspects of an exposure it is important to determine which measures are most useful in predicting distal upper extremity disorders of interest.

Force Measure Comparison

The self-report measure of RPE summarizing a job (all tasks) was not correlated (r=0.06) with the same measure (RPE) collected for the most frequently performed task. This is interesting given that the median duration of the participants' highest duration task is 27 hours and would theoretically dominate the rating based on all tasks. Since the job based RPE was collected during an interview and the task-specific RPE was taken while the worker was engaged in his or her task, recall could have a significant impact on the self-report ratings.

Additionally, the low correlation could be due to basing the job rating on a certain characteristic of a task, regardless of the duration that the task is done. Identifying what is correlated with RPE could be important in understanding the factors that drive a specific score. For example, the all task RPE was moderately correlated (r=0.42) with peak grip force suggesting that recall may be based on the highest grip force experienced versus the percent of time spent in grip, or the number of repetitions while gripping.

Self-report VAS and RPE measures collected at the task level were highly correlated (r=0.63) and probably measure similar aspects of the force exerted. The strong correlation between the VAS and the RPE, two self-report measures quantifying force is interesting, especially since they differ slightly in what they measure. The VAS is a measure of hand fatigue with the anchors being "no fatigue" and "extreme fatigue". The RPE is a measure of hand exertion with multiple anchors such as "nothing at all" , "very weak", "moderate" or "near maximal". Although both are used as a measure of force, it is possible that "fatigue" includes some aspect of the repetitiveness of the activity, or is driven by force in a particular hand posture such as grip or pinch. However, it is worth assessing whether this relationship is consistent for people doing the same task to see if ratings are descriptive of actual exposure within a task, or more indicative of an individual's perception of the exposure, and therefore only representing the experience of that individual. The other noteworthy by task RPE association was the moderate correlation with the percent time spent in heavy pinch (r=0.41). This indicates that an exertion rating may be influenced by the amount of time working in heavy pinch more than heavy grip (r=0.02). This relationship was similar for the VAS by task rating. Both the RPE and the VAS by task had moderate negative correlations with tool weight (r=-0.20;r= -0.34) and peak (r=-0.18, r=-0.18) or matching grip or pinch forces. These findings suggest that, for these jobs, the percent time performing heavy pinch was a better predictor of perceived exertion and fatigue than tool weights or peak-applied forces.

When assessing the association between the percent time spent in different hand postures, it is important to remember that the five core postures including no load, light pinch, heavy pinch, light grip, and heavy grip are not independent of the combination measures including any pinch, any grip, heavy hand postures, light hand postures, and all grip and pinch postures. For example, the percent time in heavy pinch and grip includes the percent time in heavy pinch and the percent time in heavy grip. Therefore, the associations between the dependent variables are not particularly interesting.

The percent time in no load was negatively associated with the percent time spent in other hand postures. Interestingly, the percent time in no load had moderate positive associations with tool weight, normalized peak force and matching pinch force indicating that as the magnitude of tool weight or pinch force increases, the total time spent in no load increases as well, potentially allowing for recovery. However, the sample size for these comparisons was fairly small minimizing any conclusions that can be made.

The percent time in heavy pinch had moderate negative correlations with the percent time spent in light grip and heavy grip indicating that as more time is spent in heavy pinch there is less time spent gripping, potentially due to the need for recovery from the heavy pinching, or the nature of pinching tasks. Additionally, the moderate negative correlation with tool weight could indicate that as the tool weight increases the worker is more likely to adopt a mass grip. Interestingly, the negative correlation between matching pinch force and the percent time in heavy pinch could indicate that for many workers as the matching pinch force increases, the time one is able to maintain the pinch decreases. Again the small sample size of this comparison limits any strong conclusions from being made.

The percent time spent in any pinch had a strong negative correlation with the percent time in any grip, possibly suggesting that as more time is spent in grip, physiologically less time can be spent in pinch, and vice versa. To this point, the percent time in all grip and pinch had a moderate negative correlation with tool weight, normalized peak force and matching pinch force supporting the idea that as more time is spent in grip and pinch, the magnitude of forces produced decrease.

Tool weight had positive moderate correlations with normalized peak force, matching grip and matching pinch force indicating that as tool weight increases, so does the magnitude of peak or matching grip and pinch forces, likely due to peak and matching forces including the use of tools. The strong correlations between peak grip force, normalized peak force, and matching grip or pinch force are to be expected since for many individuals, these measures are not independent of one another.

In summary, it is clear that there is a difference between the video analyzed measures of force that quantified the percent time spent over 1kg and 4kg of pinch and grip, respectively, and the direct measurement of peak force whether quantified by peak grip force, tool weight, or matching grip or pinch force, though sample size was an issue with some of the comparisons. Given this difference, analyzing which measures are most predictive of distal upper extremity disorders, then choosing the one method that is easily implemented in the field is an important step to effectively quantifying force in the field with minimal disruption in productivity and maximal usefulness in assessing for the risk of DUE's.

Repetition Measure Comparison

A very interesting finding was the extremely low correlation between the job level (all task) self-reported HAL scale and the task specific observer rated HAL scale. It is uncertain whether this lack of association is due to differences in job versus task-specific ratings, a difference in people's perception and use of the scale, or a combination of both factors. The self-report HAL scale was most closely associated with the observer-rated efforts per minute, though this association was weak.

The observer-rated HAL scale had a very strong correlation with speed of work, potentially due to the difficulty in separating speed of work from the repetitiveness of it. Interestingly, there is a negative association between the HAL scale and the repetition rate during time spent in light or heavy pinch, and a positive correlation between the HAL scale and the repetition rate while in light grip or heavy grip, with the strongest association being between the repetition rate while in heavy grip. Given that the average repetition rate in light and heavy pinch is almost twice that of light and heavy grip (Table 3), the observer is likely basing the motion of the distal upper extremity more on grips than on pinches when assigning a HAL score.

The speed of work had a positive correlation with the repetition rate in heavy grip and a negative or extremely low correlation with the repetition rate in no load, light pinch, heavy pinch and light grip, again indicating that this scale was more heavily based on the raters observation of repeated heavy grip.

Similar to what was seen in the percent time spent in no load, the repetition rate in no load had low but negative correlations with the repetition rate in all other grip and pinch postures. The repetition rate while in light pinch also had negative, yet slightly stronger, correlations with the repetition rate in heavy pinch or grip and any grip. The correlations between the repetition rate in heavy pinch and heavy grip and all other postures were extremely low indicating that these measures were indeed independent of one another.

In summary, it is clear that the repetition rate in the five hand postures allocated during video analysis were in fact measuring different aspects to ones exposure to repetition. Additionally, it appears that observer-rated measures of speed and the HAL scale are not completely independent of one another and likely reflect the difficulty in separating the speed of work from its repetitiveness. More research is needed to assess the cause of the extremely unexpected low correlation between the self-rated HAL scale and the observer-rated HAL scale to assess whether this is due to the use and perception of anchors in the scale, or the difference between rating all tasks within a job and each task separately. The correlations between observer-rated efforts per minute and the repetitions per minute using video is of concern, particularly since the overall repetition rate as analyzed by video has a strong and negative correlation with the observer rated efforts per minute. This could be due to differences in the definition of an exertion, or the ability to more accurately quantify exertions through video analysis versus real time observation.

Force & Repetition Measure Comparison

When comparing observer-rated and direct measures of force and repetition, there is a negative moderate to strong correlation between tool weight and all measures of repetition indicating that as tool weight increases, the repetition rate decreases. This is plausible given the difficulty with repeated use of heavy tools. The strong correlation between the percent time spent in any particular hand posture and the repetition rate in that hand posture could be reflective of tasks that included repetitive yet short duty cycles. This is supported by the relatively low average percent time spent in any one hand posture. As the percent time in no load increases, the repetition rate in all other hand posture decreases. Finally, of interest, is that the percent time spent in all pinch and grip postures is most closely associated with the repetition rate in any pinch posture. This could indicate that those who are exposed to increased time spent gripping or pinching are also being exposed to a high level of repetition while pinching.

Self-Report Measure of Force Comparison: VAS & RPE

The purpose of the analysis of the absolute difference between individuals' ratings of a task using the VAS and RPE scales was to better understand the relationship between these variables, including when they can be used interchangeably and when they are measuring something different. The first part of the analysis was to look at the variability of the correlation values between tasks. Interestingly, the correlation ranged drastically between strong negative to strong positive correlations. Additionally, the linear regression analysis indicated that individuals who spent more time in light pinch or had a higher repetition rate in light pinch, were more apt to have a larger difference between their ratings of the task using the visual analog scale and the rate of perceived exertion. Conversely, the individuals that had tasks with high repetition rates in light grip, or had an increase HAL scale rating had a smaller difference between their ratings of the task using the visual analog scale and rate of perceived exertion. This analysis is somewhat limited in that the number of observations was very small for some tasks.

Despite the small sample size, assessing patterns of exposure characteristics that may have contributed to the direction and strength of the correlation between the RPE and VAS ratings within tasks was informative. When grouping the tasks that had an average absolute difference between scales that was greater than one versus those that were less than one, and compared them to the average exposure for that task, it was clear that tasks that had more time allocated to heavy pinch had more similar ratings, and those that had more time in light pinch or grip had higher differences between the RPE and VAS ratings.

The relationship between exposure characteristics of tasks and self-report ratings using the VAS and RPE is important particularly since both scales are easy and efficient assessment tools in the field. The ability to infer whether a task with a consistently high VAS or RPE rating is reflecting a higher exposure to the duration of time spent in high pinch, repetition, or both would be important in applying these scales in the field.

Tables & Figures

Table 1: Exposure variable descriptive summary of time weighted average values.

Force Measures	Measurement Summary	N	Mean	SD	Min	Max	Median	Lower Tertile	Upper Tertile
Self-Report									
RPE- All Tasks	0 to 10 Scale	443	4.54	2.24	0	11	4	3	5
RPE- By Task	0 to 10 Scale	364	3.3	1.8	0.3	7.3	3.2	2.2	4.7
Visual Analog Scale	10 cm line with anchors	373	3.7	1.8	0.1	7.3	3.8	2.9	5.2
Observer-Rated									
Duration of Exertion	1,10, 20, 30, 40, 50 60, 70 , 80%	167	24.5	15.7	5.3	79.8	16.3	16.3	20.0
Direct Measure									
Tool Weight	scale or force gage	355	4.2	6.8	0.1	50.0	1.8	1.3	2.0
Peak Force- Any position	peak force of DUE- direct measured force	336	8.5	9.2	1.0	50.9	5.7	3.9	6.2
Peak Matching GRIP	avg of 3 trials of force matching in position of use	260	13.0	7.2	1.3	46.0	12.0	10.9	12.8
Peak Matching PINCH	avg of 3 trials of force matching in position of use	298	3.7	5.4	0.3	36.7	2.2	2.1	2.2
Matching GRIP %MVC	uses MVC in same position of use for calculation	101	33.8%	14.0%	3.8%	71.8%	33.2%	27.9%	36.6%
Matching PINCH %MVC	uses MVC in same position of use for calculation	149	13.3%	10.6%	2.6%	57.6%	9.0%	9.0%	9.0%
Video Analysis									
% Time No Load	0kg pinch and 0kg power	420	17.9%	14.0%	0.1%	55.9%	17.4%	6.3%	28.1%
% Time Light Pinch	<1kg force	418	27.8%	18.5%	0.3%	70.5%	20.0%	17.4%	29.0%
% Time Light Grip	<4kg force	413	9.0%	9.7%	0.1%	50.4%	8.0%	3.1%	9.4%
% Time Light Pinch or Grip		420	37.0%	15.0%	0.8%	72.7%	32.0%		
% Time Heavy Pinch	>=1kg force	420	23.2%	17.0%	0.4%	75.9%	18.9%	8.5%	34.5%
% Time Heavy Grip	>=4kg of force	390	6.3%	8.9%	0.0%	78.8%	3.5%	1.7%	4.8%
% Time Heavy pinch or Grip	>=1kg pinch or >=4kg power	421	29.0%	19.5%	1.4%	87.2%	27.8%	10.9%	43.4%
% Time Any Pinch	>0kg pinch	420	50.8%	17.2%	1.1%	91.7%	58.7%	50.2%	62.4%
% Time Any Grip	>0kg power grip	416	15.0%	14.5%	0.1%	97.6%	12.7%	6.5%	14.9%
% Time All Postures	% time in heavy & light pinch & power grip	421	65.5%	15.0%	10.4%	99.8%	64.9%	64.8%	70.9%
Posture	**Measurement Summary**	***N***	***Mean***	***SD***	***Min***	***Max***	***Median***	***Lower Tertile***	***Upper Tertile***
Self-Report									
Hand Posture	v good, g, fair, b, v bad	387	2.99	0.96	0.54	4.55	3.06	2.00	3.91
Repetition Measures	**Measurement Summary**	**N**	**Mean**	**SD**	**Min**	**Max**	**Median**	**Lower Tertile**	**Upper Tertile**
Self-Report									
Bilateral Hand Activity Level (HAL)	0 to 10 HAL Scale	444	3.83	0.92	1	6	4	3	4
Observer-rated									
Hand Activity Level (HAL)	0 to 10 HAL Scale	388	4.9	2.2	0.7	8.7	4.4	3.3	6.8
Speed of Activity	v slow; slow, fair, fast, v fast	388	3.3	1.0	0.4	5.0	3.2	2.7	4.0
Efforts/min	1 to 20	172	13.0	3.3	2.5	33.5	13.3	13.2	13.3
Video Analysis									
Reps/min No Load	reps/min: 0kg pinch and 0kg power	420	9.0	7.7	0.1	42.7	7.6	2.1	14.3
Reps/min Light Pinch	reps/min: <1kg force	419	17.1	15.0	0.3	59.6	8.7	7.9	18.6
Reps/min Light Grip	reps/min: <4kg force	412	3.7	4.3	0.0	30.5	2.7	1.1	4.3

Reps/min Light Pinch or Grip		420	20.7	13.7	1.1	59.7	14.8	10.8	33.9
Reps/ min Heavy Pinch	reps/min: >=1kg force	421	16.1	16.8	0.1	80.5	9.7	2.2	22.4
Reps/ min Heavy Grip	reps/min: >=4kg of force	390	5.3	12.8	0.0	98.1	1.7	0.7	3.6
Reps/min Heavy Pinch or Grip	reps/min: >=1kg pinch or >=4kg power	421	21.1	23.4	0.7	128.0	12.4	1.9	33.4
Reps/min Any Pinch	reps/min: >0kg pinch	421	33.2	16.1	0.4	82.4	37.8	28.5	42.0
Reps/min Any Grip	reps/min: >0kg power grip	415	8.7	14.1	0.0	106.4	4.6	1.8	7.9
Reps/min Total	reps/min: % time in heavy & light pinch & power grip	421	50.7	24.1	3.0	163.3	44.6	43.4	61.6
Computed Scales	**Measurement Summary**	**N**	**Mean**	**SD**	**Min**	**Max**	**Median**	**Lower Tertile**	**Upper Tertile**
Normalized Peak Force (NPF)	NPF and observer based HAL scale	390	2.2	1.6	0.1	7.3	1.6	1.3	2.3
HAL TLV	NPF and observer based HAL scale	370	0.5	0.3	0.1	1.0	0.6	0.3	0.7
HAL TLV-V1- Total reps/min	NPF and calc HAL scale using video reps/mins and duty cycle for heavy pinch/grip	380	0.4	0.2	0.0	1.0	0.4	0.3	0.5
HAL TLV -V2-Heavy reps/min	using video reps/mins and duty cycle for heavy pinch/grip	348	0.3	0.2	0.0	1.0	0.2	0.1	0.3
Strain Index	VAS for exertion, %time in heavy pinch/grip for duration of exertion; video reps/min in 5 postures; observer based posture & speed rating, self – report task duration	209	39.2	42.9	0.8	351.0	27.0	13.5	40.5

Table 2: Right side correlation of force variables between tasks of greatest duration (one per subject).

	RPE All tasks	RPE By Task	VAS	% Time No load	% Time Light Pinch	% Time Heavy Pinch	% Time Light Grip	% Time Heavy Grip	% Time in Heavy Pinch/ Grip	% Time in Any Pinch	% Time in Any Grip	% Time in All Pinch/ Grip
RPE: All Tasks	1.00											
	443											
RPE: By Task	0.06	1.00										
	163	166										
VAS	-0.02	0.63	1.00									
	161	156	164									
% Time No load	0.07	-0.01	-0.13	1.00								
	130	56	58	133								
% Time Light Pinch	-0.15	-0.20	-0.02	-0.27	1.00							
	130	56	58	133	133							
% Time Heavy Pinch	0.13	0.41	0.35	-0.13	-0.30	1.00						
	130	56	58	133	133	133						
% Time Light Grip	0.02	-0.01	-0.19	-0.12	-0.35	-0.27	1.00					
	130	56	58	133	133	133	133					
% Time Heavy Grip	-0.02	0.02	-0.02	-0.31	-0.39	-0.33	0.05	1.00				
	130	56	58	133	133	133	133	133				
% Time in Heavy Pinch/Grip	0.09	0.35	0.27	-0.37	-0.59	0.57	-0.19	0.59	1.00			
	130	56	58	133	133	133	133	133	133			
% Time in Any Pinch	-0.04	0.00	0.19	-0.34	0.68	0.50	-0.53	-0.61	-0.10	1.00		
	130	56	58	133	133	133	133	133	133	133		
% Time in Any Grip	0.00	0.00	-0.13	-0.31	-0.51	-0.42	0.61	0.82	0.35	-0.79	1.00	
	130	56	58	133	133	133	133	133	133	133	133	
% Time in All pinch/ grip	-0.07	0.01	0.13	-1.00	0.27	0.13	0.12	0.31	0.37	0.34	0.31	1.00
	130	56	58	133	133	133	133	133	133	133	133	133
Tool Weight	-0.04	-0.20	-0.34	0.38	0.04	-0.34	-0.17	0.15	-0.20	-0.20	-0.04	-0.38
	77	49	48	31	31	31	31	31	31	31	31	31
Peak Grip Force	0.42	-0.18	-0.18	-0.03	-0.24	-0.33	0.33	0.38	0.00	-0.42	0.45	0.03
	77	46	47	41	41	41	41	41	41	41	41	41
Normalized Peak Force	0.05	0.03	-0.07	0.29	0.14	-0.05	-0.18	-0.13	-0.18	0.06	-0.22	-0.29
	122	74	71	49	49	49	49	49	49	49	49	49
Matching Grip Force	0.29	-0.25	-0.17	0.08	0.11	-0.28	-0.04	0.17	-0.09	-0.20	0.13	-0.08
	85	48	47	38	38	38	38	38	38	38	38	38
Matching Pinch Force	0.32	0.22	0.04	0.34	-0.30	-0.20	0.04	0.73	-0.02	-0.45	0.27	-0.34
	37	26	24	11	11	11	11	11	11	11	11	11

(continued)	Tool Weight	Peak Grip Force	Normal Peak Force	Match Grip Force	Match Pinch Force
Tool Weight	1.00				
	78				
Peak Grip Force	0.37	1.00			
	54	79			
Normalized Peak Force	0.39	0.30	1.00		
	52	47	122		
Matching Grip Force	0.46	0.88	0.52	1.00	
	39	36	85	85	
Matching Pinch Force	0.38	1.00	0.73	.	1.00
	13	11	37	0	37

TABLE 3: Right Side Correlation of Repetition Variables between Tasks of Greatest Duration (one per subject)

	HAL Reps Scale (Self)	HAL Reps Scale (Obs)	Obs-rated eff/ min	Speed of Work	Reps/ min: % Time No load	Reps/ min: % Time Light Pinch	Reps/ min: % Time Heavy Pinch	Reps/ min: % Time Light Grip	Reps/ min: % Time Heavy Grip	Reps/ min: % Time in Heavy Pinch/ Grip	Reps/ min: % Time in Any Pinch
HAL Scale Reps (Self-Report)	1.00										
	444										
HAL Reps Scale (Observer-Rated)	0.05	1.00									
	178	180									
Obs-Rated eff/min	0.29	0.21	1.00								
	79	81	81								
Speed of Work	0.13	0.65	0.32	1.00							
	175	177	81	177							
Reps/min: % Time No load	0.17	-0.04	-0.73	0.10	1.00						
	129	43	6	40	131						
Reps/min: % Time Light Pinch	0.08	-0.23	0.32	0.03	0.03	1.00					
	129	43	6	40	131	131					
Reps/min: % Time Heavy Pinch	0.08	-0.12	-1.00	-0.27	-0.13	-0.22	1.00				
	129	43	6	40	131	131	131				
Reps/min: % Time Light Grip	-0.09	0.02	-0.96	-0.28	-0.12	-0.17	0.03	1.00			
	129	43	6	40	131	131	131	131			
Reps/min: % Time Heavy Grip	0.08	0.47	0.18	0.37	-0.23	-0.19	0.00	0.11	1.00		
	129	43	6	40	131	131	131	131	131		
Reps/min: % Time in Heavy Pinch/Grip	0.11	0.13	-0.98	-0.06	-0.24	-0.28	0.80	0.09	0.60	1.00	
	129	43	6	40	131	131	131	131	131	131	
Reps/min: % Time in Any Pinch	0.12	-0.25	-0.24	-0.25	-0.09	0.51	0.73	-0.10	-0.13	0.50	1.00
	129	43	6	40	131	131	131	131	131	131	131
Reps/min: % Time in Any Grip	0.05	0.41	-0.83	0.20	-0.25	-0.23	0.01	0.43	0.94	0.58	-0.15
	129	43	6	40	131	131	131	131	131	131	131
Reps/min: % Time in All pinch/ grip	0.20	-0.01	-0.61	-0.09	0.11	0.32	0.61	0.15	0.42	0.74	0.76
	129	43	6	40	131	131	131	131	131	131	131

Table 3 (continued)	Reps/ min: % Time in Any Grip	Reps/ min: % Time in All pinch / grip
Reps/min: % Time in Any Grip	1.00	
	131	
Reps/min: % Time in All pinch/ grip	0.43	1.00
	131	131

Table 4: Correlation of self-report force & repetition variables.

Correlation of Self-Report Force & Repetition Variables	RPE at Baseline-Summary- All tasks	RPE during Exposure Assessment- By Task	VAS
HAL Scale Reps (Baseline)	0.25	0.01	-0.01
	437	161	162

Table 5: Correlation of observer-rated & direct measures of force & repetition.

Correlation of Observer Rated & Direct Measure Force & Repetition Variables	Tool Weight	Peak Grip Force	Normal Peak Force	Matching Grip Force	Matching Pinch Force
Hal Reps Scale	-0.25	0.06	-0.11	-0.13	0.42
	48	41	97	69	28
Obs-Rated Eff/min	-0.36	0.38	0.12	0.35	.
	20	20	29	13	16
Speed of Work	-0.45	-0.08	-0.09	-0.07	-0.08
	46	40	96	68	28

Table 6: Correlation of video analyzed measures of force & repetition.

Correlation of Video Analyzed Measures of Force & Repetition Variables	% Time No load	% Time Light Pinch	% Time Heavy Pinch	% Time Light Grip	% Time Heavy Grip	% Time in Heavy Pinch/Grip	% Time in Any Pinch	% Time in Any Grip	% Time in All pinch/ grip
Reps/min: % Time No load	0.56	-0.04	-0.11	-0.12	-0.22	-0.27	-0.13	-0.25	-0.56
	127	127	127	127	127	127	127	127	127
Reps/min: % Time Light Pinch	-0.24	0.87	-0.28	-0.33	-0.28	-0.47	0.55	-0.42	0.24
	127	127	127	127	127	127	127	127	127
Reps/min: % Time Heavy Pinch	-0.32	-0.31	0.87	-0.21	-0.16	0.66	0.45	-0.26	0.32
	127	127	127	127	127	127	127	127	127
Reps/min: % Time Light Grip	-0.13	-0.22	-0.12	0.67	0.00	-0.11	-0.30	0.41	0.13
	127	127	127	127	127	127	127	127	127
Reps/min: % Time Heavy Grip	-0.17	-0.29	-0.17	-0.03	0.74	0.42	-0.41	0.55	0.17
	127	127	127	127	127	127	127	127	127
Reps/min: % Time in Heavy Pinch/Grip	-0.36	-0.42	0.67	-0.20	0.23	0.78	0.18	0.06	0.36
	127	127	127	127	127	127	127	127	127
Reps/min: % Time in Any Pinch	-0.46	0.25	0.66	-0.41	-0.33	0.33	0.78	-0.51	0.46
	127	127	127	127	127	127	127	127	127
Reps/min: % Time in Any Grip	-0.20	-0.35	-0.20	0.24	0.66	0.33	-0.48	0.65	0.20
	127	127	127	127	127	127	127	127	127
Reps/min: % Time in All pinch/ grip	-0.39	0.01	0.48	-0.29	0.01	0.44	0.42	-0.17	0.39
	127	127	127	127	127	127	127	127	127

Figure 1. Difference between VAS and RPE rating for the task of highest duration per subject.

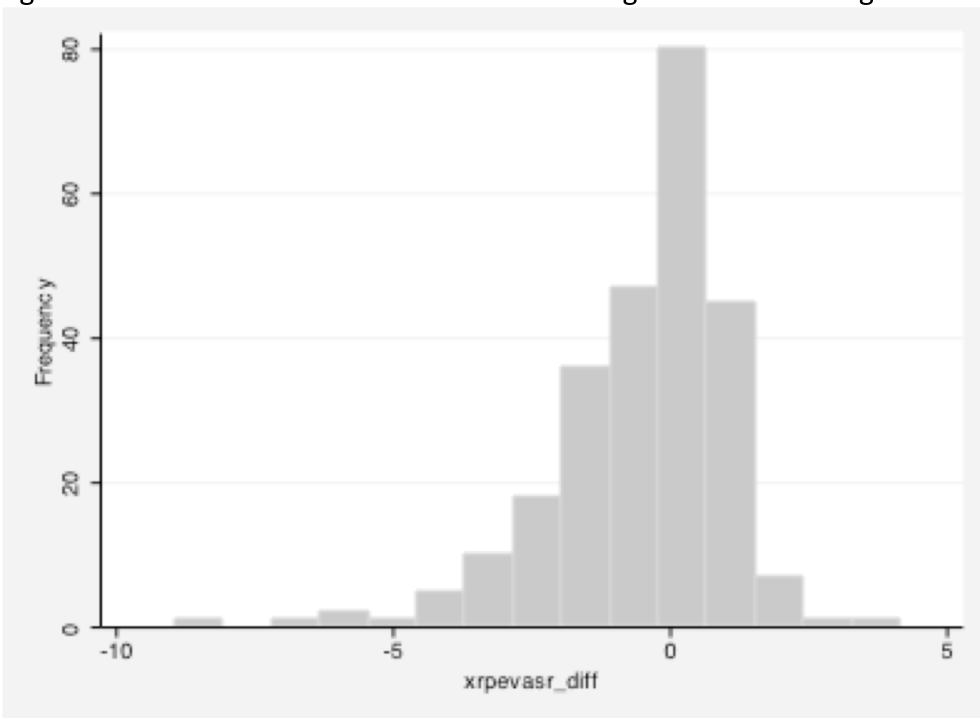


Figure 2. Absolute difference between VAS and RPE rating for the task of highest duration per subject.

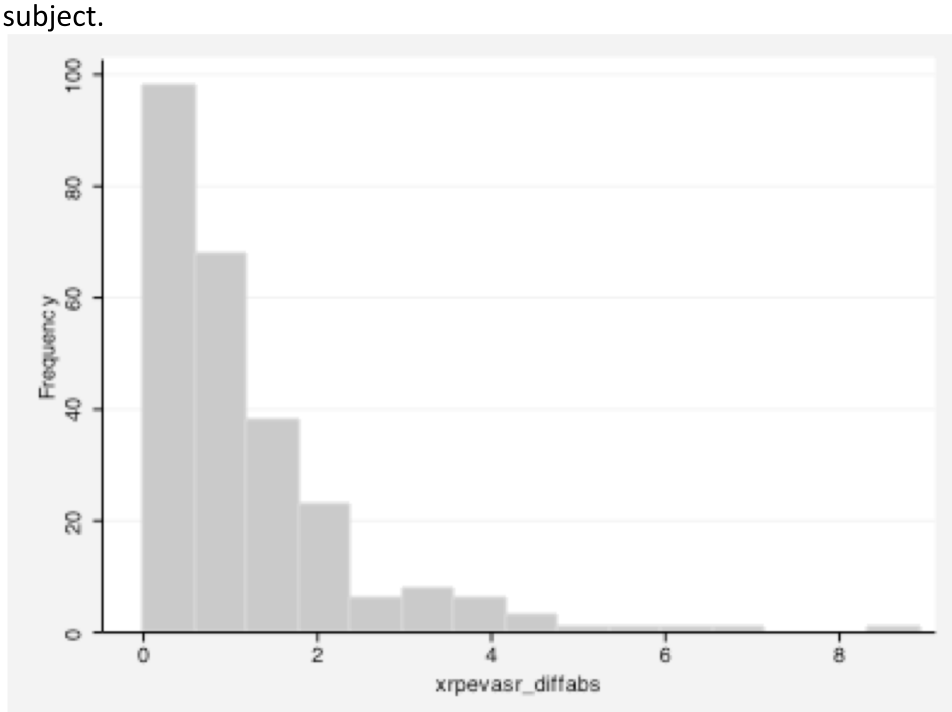


Table 7: Relationship between the absolute difference between RPE & VAS and various Exposure Variables

Measures of Force	**n**	**Correlation**	**Coef**	**Std Error**	**P value**	**Root MSE**	**R-Squared**
% Time No load	55	-0.08	-0.56	0.96	0.56	1.11	0.01
% Time Light Pinch	55	0.24	0.88	0.49	0.08	1.08	0.06
% Time Heavy Pinch	55	-0.07	-0.52	1.00	0.61	1.11	0.01
% Time Light Grip	55	-0.14	-0.95	0.96	0.33	1.10	0.02
% Time Heavy Grip	55	-0.17	-1.27	0.99	0.20	1.09	0.03
% Time in Heavy Pinch/Grip	55	-0.20	-1.14	0.79	0.15	1.09	0.04
% Time in Any Pinch	55	0.21	0.84	0.53	0.12	1.08	0.05
% Time in Any Grip	55	-0.19	-0.88	0.61	0.16	1.09	0.04
% Time in All pinch/ grip	55	0.08	0.56	0.96	0.56	1.11	0.01
Tool Weight	43	-0.21	-0.02	0.01	0.17	1.11	0.05
Peak Grip Force	45	-0.18	-0.01	0.01	0.24	1.05	0.03
Normalized Peak Force	64	-0.01	0.00	0.04	0.97	1.13	0.00
Matching Grip Force	41	0.16	0.01	0.01	0.31	0.74	0.03
Matching Pinch Force	23	-0.14	-0.01	0.02	0.51	1.53	0.02
Measures of Repetition	**n**	**Correlation**	**Coef**	**Std Error**	**P value**	**Root MSE**	**R-Squared**
Hal Reps Scale	114	-0.27	-0.27	0.09	0.00	1.43	0.07
Obs-Rated eff/min	68	0.17	0.15	0.10	0.15	1.69	0.03
Speed of Work	11	-0.11	-0.21	0.19	0.27	1.49	0.01
Reps/min: % Time No load	55	-0.07	-0.01	0.02	0.63	1.11	0.00
Reps/min: % Time Light Pinch	55	0.23	0.01	0.01	0.09	1.08	0.05
Reps/min: % Time Heavy Pinch	55	-0.13	-0.01	0.01	0.36	1.10	0.02
Reps/min: % Time Light Grip	55	-0.24	-0.04	0.02	0.08	1.08	0.06
Reps/min: % Time Heavy Grip	55	-0.13	-0.01	0.01	0.36	1.10	0.02
Reps/min: % Time in Heavy Pinch/Grip	55	-0.18	-0.01	0.01	0.18	1.09	0.03
Reps/min: % Time in Any Pinch	55	0.17	0.01	0.01	0.21	1.09	0.03
Reps/min: % Time in Any Grip	55	-0.20	-0.01	0.01	0.14	1.09	0.04
Reps/min: % Time in All pinch/ grip	55	0.01	0.00	0.01	0.92	1.11	0.00

TABLE 8: Average within task exposure values, correlations, and absolute differences between VAS & RPE self-rating scales.

TASK		RPE & VAS: CORRELATION WITHIN TASK		RPE & VAS: ABSOLUTE DIFFERENCE WITHIN TASK			% Time No load	% Time Light Pinch	% Time Heavy Pinch	% Time Light Grip	% Time Heavy Grip	% Time in Any Grip	% Time in Any Pinch	% Time in All pinch/ grip
ID	**N**	**n**	**Correlation**	**Mean**	**SD**	**N**	**Avg**	**Avg**	**Avg**	**Avg**	**Avg**	**Avg**	**Avg**	**Avg**
5	6	3	-0.46	1.91	2.07	2	0.49	0.28	0.06	0.17	0.01	0.06	0.34	0.51
6	13	5	0.67	1.05	0.61	5	0.16	0.08	0.15	0.22	0.39	0.54	0.23	0.84
7	12	4	-0.89	2.29	1.32	3	0.21	0.36	0.27	0.06	0.10	0.37	0.63	0.79
21	12	3	-0.46	1.30	1.19	4	0.17	0.09	0.12	0.30	0.36	0.44	0.21	0.83
22	13	11	0.42	1.07	0.89									
79	12	6	0.78	2.58	1.67	7	0.14	0.43	0.41	0.02	0.00	0.42	0.84	0.87
92	85	67	0.51	1.74	1.74	13	0.03	0.82	0.13	0.01	0.02	0.15	0.95	0.97
93	19	11	0.50	1.25	1.25	1	0.03	0.85	0.09	0.01	0.02	0.11	0.95	0.97
107	8	4	0.98	0.67	0.46	1	0.12	0.02	0.03	0.76	0.08	0.11	0.04	0.88
131	106	17	0.92	0.52	0.53	28	0.09	0.30	0.46	0.10	0.05	0.51	0.76	0.91
132	113	9	0.90	0.65	0.58	21	0.30	0.15	0.40	0.12	0.03	0.43	0.55	0.70
133	124	7	0.94	0.42	0.24	23	0.41	0.11	0.39	0.05	0.03	0.43	0.51	0.59
137	12	6	0.83	0.47	0.36	6	0.04	0.22	0.56	0.16	0.03	0.59	0.77	0.96
140	8	4	0.70	0.93	0.64	4	0.07	0.01	0.16	0.15	0.62	0.78	0.17	0.94
141	14	7	0.69	0.67	0.51	2	0.39	0.03	0.32	0.18	0.08	0.40	0.35	0.61
143	25	7	-0.09	0.70	0.73	10	0.03	0.17	0.56	0.07	0.17	0.73	0.73	0.97
144	25	5	0.90	0.40	0.23	9	0.08	0.10	0.10	0.50	0.23	0.32	0.19	0.92
145	28	4	0.88	0.29	0.13	9	0.01	0.08	0.85	0.05	0.01	0.87	0.94	0.99
Average(abs diff>1)							0.17	0.42	0.17	0.11	0.13	0.30	0.59	0.83
Average (abs diff<1)							0.15	0.12	0.38	0.21	0.13	0.52	0.50	0.85

Cross Sectional Analysis

Introduction

No causal inferences can be made between exposures and outcome evaluated at the same point in time, however prevalence studies can provide useful assessments of the burden of disease in a population and may identify work-related factors and employee characteristics associated with the disease. This approach is also more useful when the exposure variables are stable over a long time period. In analyzing this cohort at baseline, the occurrence of right wrist tendinosis and its association with various demographic, job, psychosocial, and exposure factors is important in understanding additional factors that contribute to the duration of disease that differ from those that cause it.

Methods of Statistical Analysis

Logistic regression was used to model the log odds of tendinosis at baseline, as a function of exposure variables and relevant confounders. Exposure variables quantifying repetition and force were divided into tertiles based on equal cases in high, medium and low exposure groups. The ACGIH-TLV for hand activity level was applied using standard cutoffs of 0.56 and 0.78, and the strain index was divided using a standard cutoff of 3 and 7. Potential confounders associated with the outcome ($p<0.2$) or with the primary exposure ($r>0.3$) were included then sequentially removed. Variables that changed the odds ratio (OR) for exposure by more than 10% were retained in the final model. Model comparisons were based on multivariate models that had the strongest associations with right wrist tendinosis and included the same adjustments for covariates of interest.

Results

Prevalence

At baseline, there were 140 participants who reported symptoms of pain in the hand or wrist on either the right or left side that met the pain criteria (Table 1). On the right side, 130 individuals were symptomatic and the prevalence of right hand or wrist pain in this population was 28.9 per 100 persons.

Based on physical examinations, there were 37 workers with right wrist tendinosis at baseline with a prevalence of 8.2 cases per 100 people (Table 1). Wrist extensor tendinosis (n=30) was approximately three times more common than wrist flexor tendinosis (n=7) cases. The prevalence for right wrist flexor tendinosis was 1.56 cases per 100 people versus 6.67 cases per 100 people for right wrist extensor tendinosis. Right flexor carpi ulnaris tendinosis was the most common (n=5) wrist flexor tendon affected and tendinosis of the 1st dorsal compartment (de Quervains Syndrome) had the highest extensor tendon and overall prevalence (n=18).

Univariate Analysis: Demographic & Work Psychosocial Variables

Demographic Variables. The odds ratio for right wrist tendinosis if female was 1.99 (95% CI: 1.01-3.92) and for being over 40 years of age was 0.81 (95% CI: 0.41-1.60). Hispanic participants had 3.11(95% CI: 0.73-13.28) increased odds of being a case than non-Hispanic participants (Table 2), and those with a BMI greater than 30 had an increased odds ratio 1.38

(95% CI: 0.69-2.77) compared to those with a BMI less than 30. Right-handed individuals had an elevated odds ratio of 1.35 (95% CI: 0.17-10.55) compared to left-handed individuals, and those with medical conditions had 1.21 (95% CI: 0.41-3.61) greater odds than those without a medical condition. Those on the birth control pill had 1.92 (95% CI: 0.17-16.18) times the odds of having right wrist tendinosis than those who were not taking the birth control pill, and those on a medication had 3.8 (95% CI: 0.78-24.18) times greater odds than those who were not on any medication. Those who were current smokers had 1.63 (95% CI: 0.71-3.75) times the odds of being a case than those who were previous smokers or had never smoked at all. Participants who engaged in any physical hand intensive (such as house chores or sewing) or aerobic activity (such as jogging, or swimming) more than one hour per week had 1.79 (95% CI: 0.87-3.68) times the odds of being a case than those who were not active, and those who reported fair or better overall health had 0.93(95% CI: 0.45-1.95) the odds than those who reported fair health. Individuals with a high school diploma had a reduced risk (OR=0.9;95% CI: 0.42-1.92) of having right wrist tendinosis than those who did not, and annual income did not affect the ones risk of having wrist tendinosis.

Work Psychosocial Variables. Workers on the day shift had 1.55 (95% CI: 0.72-3.3) times greater odds of having right wrist tendinosis than workers on any other shift, and workers with high job strain (0.73, 95% CI: 0.32-1.64) or high iso-strain (0.86, 95% CI: 0.32-2.3) had slightly decreased risk of being a case than those with low job-strain or low iso-strain, respectively. Workers with 2 to 5 years of experience doing the same job had 1.46 (95% CI: 0.56-3.80) times the risk of having right wrist tendinosis than those working less than 2 years, and those with more than 5 years of experience had decreased risk (OR=0.85;95% CI: 0.36-2.03) of being a case than those working less than 2 years.

Workers who were satisfied with their job had 0.33 (95% CI: 0.13-0.81) decreased odds of being a case than those who reported being unsatisfied. In comparison to workers at the dairy manufacturing site, workers at the chair manufacturing plant had 1.62 (95% CI: 0.31-8.56) greater odds, workers at the mushroom growing facility had 1.43 (95% CI: 0.39-5.21) times the odds, and workers at the stone manufacturing plant had 1.82 (95% CI: 0.52-6.45) times the odds of having right wrist tendinosis at baseline.

Univariate Analysis: Exposure Variables

Force Measures.

Self-Report. RPE values had an odds ratio of 1.76 (95% CI: 0.7-4.43) and 0.87 (95% CI: 0.35-2.17) for medium and high groups, respectively and VAS ratings for hand fatigue had an odds ratio of 2.47 (95% CI: 0.99-6.13) and 1.03 (95% CI: 0.42-2.5) for medium and high groups (Table 3).

Direct Measure. Tool weight had an odds ratio of 2.01(95% CI: 0.79-5.12) and 2.82(95% CI: 1.09-7.28) for medium and high groups. Peak hand force and normalized peak force had odd ratios of 0.93 (95% CI: 0.36-2.42) and 1.06 (95% CI: 0.44-2.53) for medium groups, and 1.49 (95% CI: 0.55-4.05) and 1.15 (95% CI: 0.48-2.77) for high groups, respectively.

Video Analysis. Video based assessments of percent time spent in no load had an odds ratio of 1.01 (95% CI: 0.44-2.33) and 0.75 (95% CI: 0.32-1.77) for medium and high groups. The percent time spent in light pinch had an odds ratio of 0.54 (95% CI: 0.23-1.26) and 0.63 (95% CI: 0.27-1.49) and the percent time spent in heavy pinch had an odds ratio of 2.43 (95% CI: 1.95-

5.64) and 1.54 (95% CI: 0.66-3.61) for medium and high groups, respectively. The percent time spent in light grip had an odds ratio of 0.78 (95% CI: 0.34-1.81) and 1.05 (95% CI: 0.44-2.47) and the percent time spent in heavy grip had an odds ratio of 0.56 (95% CI: 0.23-1.35) and 0.79 (95% CI: 0.34-1.88) for medium and high groups, respectively. The percent time spent in either heavy pinch or heavy grip had an odds ratio of 2.43 (95% CI: 1.05-5.66) for the medium group and 1.25 (95% CI: 0.54-2.92) for the high group. The percent time spent in all pinch and grip postures had an odds ratio of 0.58 (95% CI: 0.25-1.33) and 1.35 (95% CI: 0.56-3.2), for medium and high groups, respectively.

Repetition Measures.

Observer-Rated. The HAL scale had an odds ratio of 2.06 (95% CI: 0.85-4.99) and 0.95 (95% CI: 0.4-2.27) for medium and high groups, respectively. The speed of activity had an odds ratio of 0.68 (95% CI: 0.28-1.63) and 0.84 (95% CI: 0.35-2.03), for medium and high groups (Table 3).

Video Analysis. Video based assessments of repetition rate while in no load had an odds ratio of 1.00 (95% CI: 0.43-2.31) and 0.89 (95% CI: 0.38-2.09) for medium and high groups. The repetition rate while in light pinch had an odds ratio of 0.48 (95% CI: 0.21-1.11) and 0.58 (95% CI: 0.24-1.37) and the repetition rate while in heavy pinch had an odds ratio of 1.92 (95% CI: 0.82-4.45) and 1.01 (95% CI: 0.43-2.36) for medium and high groups. The repetition rate while in light grip had an odds ratio of 0.86(95% CI: 0.37-1.97) and 1.25(95% CI: 0.53-2.96) and the repetition rate while in heavy grip had an odds ratio of 0.9(95% CI: 0.38-2.12) and 0.81(95% CI: 0.33-1.98) for medium and high groups, respectively. The repetition rate while in either heavy pinch or heavy grip had an odds ratio of 2.88(95% CI: 1.23-6.72) for the medium group and 1.28(95% CI: 0.55-2.99 for the high group. The repetition rate while in all pinch and grip postures had an odds ratio of 1.14(95% CI: 0.48-2.69) and 1.87(95% CI: 0.82-4.24), for medium and high groups.

Composite Measures.

Posture. The odds ratio for hand posture in the high exposure group was 1.01 (95% CI: 0.43-2.42) and 1.78 (95% CI: 0.74-4.3) in the medium group.

HAL-TLV. The HAL-TLV scores generated by using the normalized peak force score and the observer-rated HAL scale, using standard cutoffs of 0.56 and 0.78 to separate low, medium, and high groups, had an odds ratio of 1.23 (95% CI: 0.55-2.73) for the medium group and 1.46 (95% CI: 0.49-4.31) for the high group. The HAL-TLV score generated with the normalized peak force and repetition rate while in heavy pinch and grip, using standard cutoffs, had an odds ratio of 1.01(95% CI: 0.37-2.76) and 1.64(95% CI: 0.53-5.08) for medium and high exposure groups (Table 3).

Strain Index. There was only one right wrist tendinosis case with a strain index value less than 7 and no cases with a strain index under 3 preventing a comparison using a cutoff of 3. Using 7 as a cutoff, the high group had an odds ratio of 1.82 (95% CI: 0.51-6.5).

Multivariate Analysis

The three exposure variables quantifying force selected to continue in separate multivariate models were the self-report measure of the VAS, the direct measure of tool weight, and the video analysis measure of the percent time spent in heavy pinch. Additionally, models compared the percent time in heavy pinch, heavy pinch or grip, all pinch and grip, and light pinch.

The three exposure variables quantifying repetition selected to continue in separate multivariate models included the observer-rated HAL scale and the video analysis measures of the repetition rate while in all postures and while in heavy pinch and grip. Additionally, a model compared the repetition rate in heavy pinch, heavy pinch or grip, light pinch and total repetitions.

The final covariates kept in all models were age, gender, activity level, and job satisfaction. Ethnicity was removed from the models due to instability associated with the small number of cases in the non-Hispanic study population. None of the other variables were correlated at a level with the outcome to consider in the model.

Force Measures. The multivariate model for the VAS for hand fatigue had an odds ratio of 2.67 (95%CI: 1.03-6.94) and 1.16 (95%CI: 0.45-3.00) for medium and high groups. The multivariate model including the tool weight had an odds ratio of 2.21 (95%CI: 0.82-5.92) and 2.38 (95%CI: 0.89-6.39) for medium and high groups. The multivariate model including the percent time spent in heavy pinch had an odds ratio of 2.67 (95%CI: 1.08-6.60) and 1.74 (95%CI: 0.71-4.25) for medium and high groups (Figure 1a). The model with percent time in heavy pinch was compared to models with the percent time spent in other hand postures, including the same covariates (Figure 1b). The odds ratio for the percent time in heavy pinch and grip was similar to that of heavy pinch. The percent time in light pinch was protective for both the medium and high groups (OR=0.67; 95%CI: 0.28-1.62 and OR=0.44; 95%CI: 0.18-1.12)

Repetition Measures. The multivariate model for the HAL repetition scale had an odds ratio of 2.13 (95%CI: 0.84-5.38) and 1.15 (95%CI: 0.44-3.02) for medium and high groups. The multivariate model including the repetition rate while in heavy pinch and grip had an odds ratio of 3.44 (95%CI: 1.36-8.72) and 1.51 (95%CI: 0.61-3.7) for medium and high groups (Figure 2a). A comparison to models for repetition rate while in other hand postures, using the same covariates is shown in Figure2b. The odds ratio for the total repetition rate was 1.38 (95% CI: 0.56-3.42) and 1.89 (95%CI: 0.78-4.57), for medium and high groups. The repetition rate while in light pinch was protective for medium (OR=0.43; 95%CI: 0.18-1.02) and high groups (OR=0.36; 95%CI: 0.14-0.97).

Force & Repetition Measures. When adjusting the percent time in heavy pinch or grip model for repetition measured via the observer-rated HAL scale, the repetition rate in heavy pinch or grip, and total repetition rate, (Figure 3a), the hazard ratios for percent time in heavy pinch or grip increased to between 3.5 (95%CI: 1.2-10.2) and 1.46 (95% CI: 0.45-4.71) for medium groups and were close to 1 for high exposure groups, regardless of the method used for quantifying repetition. Results were similar for models analyzing the percent time in heavy pinch and controlling for repetition measured via the observer-rated HAL scale, the repetition rate in heavy pinch, and total repetition rate (Figure 3b). The odds ratios for medium and high groups were between 1.9 to 2.43 and 1.3 to 2.19, depending on the method used for quantifying repetition, yet none of them were significant.

Composite Measures. Different measures of the HAL-TLV using standard cutoffs of 0.56 and 0.78 to separate low, medium and high groups yielded similar results, despite the method of quantifying repetition being different. All odds ratios were close to one for medium and high groups in all three models (Figure 4).

Discussion

Understanding the various factors associated with the prevalence of a disease is important in identifying factors that may contribute to the length of disease and its overall burden in a population. If factors that are strongly associated with the prevalence of a disease are mitigated, then the length of time that one has the disease and the overall cost of the disease may be reduced.

The majority of the thirty-seven prevalent cases at baseline were wrist extensor tendinoses with approximately half of all being tendinosis of the 1st Dorsal Compartment. The demographic factors that were associated with the prevalence of wrist tendinosis included being female, doing an hour or more of hand intensive activity per week, and having low job satisfaction. Women often experience greater prevalence of distal upper extremity disorders, a finding that was evident in this study. Interestingly, job satisfaction has been shown to be associated with various injuries and workers compensation claims (Leclerc et al., 2001) though it is not possible to determine the direction of causality between the variables with cross sectional studies. For example, it is plausible that job satisfaction decreases as a result of a worker experiencing pain, versus an unhappy worker being more susceptible to experiencing pain. Regardless, job satisfaction could be an important indicator of a worker whose wrist tendinosis has not been resolved. It would be interesting to investigate whether job satisfaction predicts the duration of wrist tendinosis, their quality of life, and or their ability to do their normal job.

The majority of individuals reporting weekly activity engaged in house cleaning and child care activities which likely involved hand intensive tasks, potentially placing the workers at increased risk for having wrist tendinosis, and potentially increasing the duration of injury by preventing sufficient rest and recovery time when not at work.

When comparing the various measures of force in models that included the same covariates, it was interesting that the medium exposure groups all had similar odds ratios whether the measurement was based on a self-reported visual analog scale, tool weight, or the percent time in heavy pinch. Another interesting finding was the variability of the odds ratios for the VAS for hand fatigue in the high exposure group. Although tool weight and the percent time in heavy pinch were both relatively high, the VAS odds ratio was very close to 1. This may reflect individual's reluctance to use the far ends of a rating scale.

The comparison of the percent time spent in different hand postures including heavy pinch, heavy pinch or grip, all pinch and grip, and light pinch or grip, showed that the prevalence of wrist tendinosis was associated with the percent time in heavy pinch and grip, and as more time was spent in light pinch or light grip, the risk of having wrist tendinosis decreased. This relationship may be due to a tradeoff of exposures; i.e., those with more light hand activities had exposure to heavy hand activities and visa versa.

The protective factor of spending time in light pinch and grip was also seen for repetition indicating that it may be a combination of force and repetition that was responsible for the protective relationship. The other interesting finding was that repetition in heavy pinch and grip was associated with the prevalence of wrist tendinosis, particularly in the medium exposure group. It was interesting that the high exposure group had a lower risk of having wrist tendinosis than the medium group. The same pattern was seen when quantifying repetition using the HAL scale, or basing repetition rate on heavy pinch actions alone. This could be due to workers who have high exposure jobs to self-select out of those jobs due to their discomfort or injury, and those who are moderately exposed may be able to manage the discomfort while continuing their normal work. More analysis of factors that are associated with work disability may be helpful in understanding this finding.

In the multivariate models analyzing the percent time in heavy pinch or grip, or percent time in heavy pinch alone, while controlling for repetition, similar patterns of risk are seen, however, the odds ratios actually decrease. This supports the idea that both forceful hand postures and the repetition rate in those postures contribute to the prevalence of wrist tendinosis and that removing either factor reduces the risk of a worker having right wrist tendinosis.

Tables & Figures

Table 1: Prevalence of right wrist tendinosis at baseline.

Cross Sectional Wrist Tendinosis Summary	BASELINE N=450						
	N	**Left Side**	**Right Side**	**Either Side**	**Left Side Prevalence/ 100 people (SE)**	**Right Side Prevalence/ 100 people (SE)**	**Either Side Prevalence/ 100 people (SE)**
Hand/Wrist Symptoms	450	114	130	140	25.33	28.89	31.11
Number of Physical Exams	450	105	115	137			
Total Hand/Wrist Tendonitis Disorders/Cases	**450**	**28**	**37**	**53**	**6.22**	**8.22**	**11.70**
Flexor Tendonitis	**450**	**8**	**7**	**14**	**1.78**	**1.56**	**3.09**
Flexor Carpi Radialis Tendonitis	450	1	2	3	0.22	0.44	0.66
Flexor Carpi Ulnaris Tendonitis	450	4	5	8	0.89	1.11	1.77
Flexor Digitorum Tendonitis	450	2	0	2	0.44	0.00	0.44
Trigger Finger	450	3	2	5	0.67	0.44	1.10
Extensor Tendonitis	**450**	**24**	**30**	**43**	**5.33**	**6.67**	**9.56**
Dorsal Compartment 1	450	13	18	24	2.89	4.00	5.33
Dorsal Compartment 2	450	7	7	12	1.56	1.56	2.67
Dorsal Compartment 3	450	2	4	6	0.44	0.89	1.33
Dorsal Compartment 4	450	1	6	6	0.22	1.33	1.33
Dorsal Compartment 5	450	0	0	0	0.00	0.00	0.00
Dorsal Compartment 6	450	4	2	6	0.89	0.44	1.33
Intersection Syndrome	450	0	1	1	0.00	0.22	0.22

Table 2: Univariate analysis: demographic variables and right wrist tendinosis.

Participant Demographics: Cross Sectional Cohort & Right Wrist Tendinosis (N=450)	**N (Right Side Analysis)**	**Right Side Cases**	**Controls**	**Cases/100 people**	**OR**	**p-value**	**Lower CI**	**Upper CI**
Gender	**450**	**37**	**413**					
Male	288	18	270	7	1.00			
Female	162	19	143	13	1.99	**0.05**	1.01	3.92
Age (years)	**450**	**37**	**413**					
<40 years of age	234	21	213	10	1.00			
>=40 years of age	216	16	200	8	0.81	0.55	0.41	1.60
Ethnicity	**435**	**37**	**398**					
Non-Hispanic	62	2	60	3	1.00			
Hispanic	373	35	338	10	3.11	**0.13**	0.73	13.28
Body Mass Index	**441**	**36**	**405**					
Body Mass Index (<30)	288	21	267	8	1.00			
Body Mass Index (>30: obese)	153	15	138	11	1.38	0.36	0.69	2.77
Handedness	**440**	**36**	**404**					
Left- handed	16	1	15	7	1.00			
Right-handed	424	35	389	9	1.35	0.78	0.17	10.55
Medical History	**444**	**37**	**407**					
No Medical Condition	403	33	370	9	1.00			
Medical Condition	41	4	37	11	1.21	0.73	0.41	3.61
No Gout, RA, Lupus	429	36	393	9	1.00			
Gout, RA, Lupus	13	1	12	8	0.91	0.93	0.11	7.21
No Diabetes	415	34	381	9	1.00			
Diabetes	28	3	25	12	1.34	0.64	0.39	4.69
No Hyper/Hypothyroidism	437	37	400	9	1.00			
Hyper/Hypothyroidism	4	0	4	0	0.00	.	.	.
Not currently Pregnant	79	9	70	13	1.00			
Currently Pregnant	1	0	1	0	0.00	.	.	.
No Birth Control Pill	74	8	66	12	1.00			
Birth Control Pill	6	1	5	20	1.65	0.67	0.17	16.18
No Medication*	154	11	143	8	1.00			
Medication*	8	2	6	33	4.33	**0.10**	0.78	24.18
Smoking Status	**445**	**37**	**408**					
Never/Previously smoked	378	29	349	8	1.00			
Currently Smokes	67	8	59	14	1.63	0.25	0.71	3.75
Activity	**434**	**36**	**398**					
< 1 hour/week	200	12	188	6	1.00			
>=1 hour/week	234	24	210	11	1.79	**0.11**	0.87	3.68
Overall Health Status	**436**	**37**	**399**					
Poor	124	11	113	10	1.00			
Fair or better	312	26	286	9	0.93	0.86	0.45	1.95
Educational Level	**442**	**36**	**406**					
Some or no highschool	310	26	284	9	1.00			
Highschool graduate or higher	132	10	122	8	0.90	0.78	0.42	1.92
Annual Income	**306**	**26**	**280**					
<30k per year	154	13	141	9	1.00			
>= 30k per year	152	13	139	9	1.01	0.97	0.45	2.27
Shift	**441**	**36**	**405**					
Swing/Night/Rotating Shift	161	10	151	7	1.00			
Day Shift	280	26	254	10	1.55	0.26	0.72	3.30
Job Strain	**429**	**37**	**392**					
Low Job Strain	313	29	284	10	1.00			

High Job Strain	116	8	108	7	0.73	0.44	0.32	1.64
Iso Strain	**427**	**37**	**390**					
Low Iso Strain	362	32	330	10	1.00			
High Iso Strain	65	5	60	8	0.86	0.76	0.32	2.30
Years at Job	**450**	**37**	**413**					
<2 years	98	8	90	9	1.00			
>=2 years & < 5 Years	96	11	85	13	1.46	0.44	0.56	3.80
> 5 years	256	18	238	8	0.85	0.72	0.36	2.03
Job Satisfaction	**431**	**37**	**394**					
Unsatisfied	35	7	28	25	1.00			
Satisfied	396	30	366	8	0.33	**0.02**	0.13	0.81
Job Site	**450**	**37**	**413**					
Site 1	55	3	52	6	1.00			
Site 2	35	3	32	9	1.62	0.57	0.31	8.56
Site 3	171	13	158	8	1.43	0.59	0.39	5.21
Site 4	189	18	171	11	1.82	0.35	0.52	6.45
H/W Tendinosis at Baseline	**450**	**37**	**413**					

Table 3: Univariate analysis: exposure variables and right wrist tendinosis.

EXPOSURE VARIABLES: TIME WEIGHTED AVERAGE	N (TOTAL)	Cases	Controls	Cutoff Values	OR	p-value	Lower CI	Upper CI
REPETITION MEASURES								
Hand Activity Level Scale (0 to 10)	388	33	355					
Low	151	11	140	<=3.33	1.00			
Medium	79	11	68	>3.33 & <=5.27	2.06	**0.11**	0.85	4.99
High	158	11	147	>5.27	0.95	0.91	0.40	2.27
Efforts/min	172	13	159					
Low	70	10	60	<=13.33	1.00			
High	102	3	99	>13.33	0.18	**0.01**	0.05	0.69
Speed of Activity (0 to 5)	388	33	355					
Low	108	11	97	<=2.6	1.00			
Medium	154	11	143	>2.6 & <=4	0.68	0.38	0.28	1.63
High	126	11	115	>4	0.84	0.70	0.35	2.03
Reps/min: % Time No Load	420	35	385					
Low	139	12	127	<=1.93	1.00			
Medium	139	12	127	>1.93&<=13.77	1.00	1.00	0.43	2.31
High	142	11	131	>13.77	0.89	0.79	0.38	2.09
Reps/min: % Time Light Pinch	419	35	384					
Low	94	12	82	<=5.59	1.00			
Medium	184	12	172	>5.59 & <=17.37	0.48	**0.09**	0.21	1.11
High	141	11	130	>17.37	0.58	0.21	0.24	1.37
Reps/min: % Time Heavy Pinch	421	35	386					
Low	171	12	159	<=4.46	1.00			
Medium	95	12	83	>4.46 & <=19.03	1.92	**0.13**	0.82	4.45
High	155	11	144	>19.03	1.01	0.98	0.43	2.36
Reps/min: % Time Light Grip	412	35	377					
Low	142	12	130	<=1.20	1.00			
Medium	164	12	152	>1.2 & <=4.33	0.86	0.71	0.37	1.97
High	106	11	95	>4.33	1.25	0.61	0.53	2.96
Reps/min: % Time Heavy Grip	390	33	357					
Low	118	11	107	<=0.33	1.00			
Medium	142	12	130	>0.33 & <=3.61	0.90	0.81	0.38	2.12
High	130	10	120	>3.61	0.81	0.65	0.33	1.98
Reps/min: % Time Heavy Pinch & Grip	421	35	386					
Low	199	12	187	<=9.31	1.00			
Medium	77	12	65	>9.31 & <=28.39	2.88	**0.02**	1.23	6.72
High	145	11	134	>28.39	1.28	0.57	0.55	2.99
Reps/min: % Time Any Pinch	421	35	386					
Low	133	12	121	<=25.52	1.00			
Medium	155	12	143	>25.32 & <=43.02	0.85	0.70	0.37	1.95
High	133	11	122	>43.02	0.91	0.83	0.39	2.14
Reps/min: % Time Any Grip	415	35	380					
Low	141	12	129	<=2	1.00			
Medium	178	12	166	>2 & <=9.54	0.78	0.55	0.34	1.79
High	96	11	85	>9.54	1.39	0.45	0.59	3.30
Reps/min: % Time All Pinch & Grip	421	35	386					
Low	216	15	201	<=44.59	1.00			
Medium	115	9	106	>44.59 & <=62.09	1.14	0.77	0.48	2.69

High	90	11	79	>62.09	1.87	**0.14**	0.82	4.24
FORCE MEASURES								
Rate of Perceived Exertion (0 to 10)	364	30	334					
Low	133	10	123	<=2.67	1.00			
Medium	80	10	70	>2.67 & <=3.42	1.76	0.23	0.70	4.43
High	151	10	141	>3.42	0.87	0.77	0.35	2.17
Visual Analog Scale (0 to 10)	373	31	342					
Low	163	11	152	<=3.48	1.00			
Medium	66	10	56	>3.48 & <=4.66	2.47	**0.05**	0.99	6.13
High	144	10	134	>4.66	1.03	0.95	0.42	2.50
% Time No Load	420	35	385					
Low	132	12	120	<=4.5%	1.00			
Medium	131	12	119	>4.5% & <=27%	1.01	0.98	0.44	2.33
High	157	11	146	>27%	0.75	0.52	0.32	1.77
% Time Light Pinch	418	35	383					
Low	101	12	89	<=13.8%	1.00			
Medium	176	12	164	>13.8% & <=28.6%	0.54	**0.15**	0.23	1.26
High	141	11	130	>28.6%	0.63	0.29	0.27	1.49
% Time Heavy Pinch	420	35	385					
Low	204	12	192	<=16.9%	1.00			
Medium	91	12	79	>16.9% & <=39.5%	2.43	**0.04**	1.05	5.64
High	125	11	114	>39.5%	1.54	0.32	0.66	3.61
% Time Light Grip	413	35	378					
Low	132	12	120	<=2.5%	1.00			
Medium	165	12	153	>2.5% & <=10%	0.78	0.57	0.34	1.81
High	116	11	105	>10%	1.05	0.92	0.44	2.47
% Time Heavy Grip	390	33	357					
Low	110	12	98	<=1.2%	1.00			
Medium	156	10	146	>1.2% & <=5.1%	0.56	**0.19**	0.23	1.35
High	124	11	113	>5.1%	0.79	0.60	0.34	1.88
% Time Heavy Pinch & Grip	421	35	386					
Low	192	12	180	<=21.3%	1.00			
Medium	86	12	74	>21.3% & <=42.8%	2.43	**0.04**	1.05	5.66
High	143	11	132	>42.8%	1.25	0.61	0.54	2.92
% Time Any Pinch	420	35	385					
Low	149	12	137	<=51.5%	1.00			
Medium	126	12	114	>51.5% & <=61.5%	1.20	0.67	0.52	2.78
High	145	11	134	>61.5%	0.94	0.88	0.40	2.20
% Time Any Grip	416	35	381					
Low	140	12	128	<=6.8%	1.00			
Medium	159	12	147	>6.8% & <=18.3%	0.87	0.75	0.38	2.01
High	117	11	106	>18.3%	1.11	0.82	0.47	2.61
% Time All Pinch & Grip	421	35	386					
Low	125	12	113	<=63%	1.00			
Medium	208	12	196	>63% & <=71.9%	0.58	**0.20**	0.25	1.33
High	88	11	77	>71.9%	1.35	0.50	0.56	3.20
Tool Weight (kg)	355	28	327					
Low	195	10	185	<=0.9	1.00			
Medium	92	9	83	>0.9 & <=1.52	2.01	**0.15**	0.79	5.12

High	68	9	59	>1.52	2.82	**0.03**	1.09	7.28
Peak Force Hand (kg)	336	26	310					
Low	125	9	116	<=2.17	1.00			
Medium	134	9	125	>2.17 & <=4.14	0.93	0.88	0.36	2.42
High	77	8	69	>4.14	1.49	0.43	0.55	4.05
Normalized Peak Force (0 to 10)	390	33	357					
Low	138	11	127	<=1.36	1.00			
Medium	131	11	120	>1.36 & <=2.69	1.06	0.90	0.44	2.53
High	121	11	110	>2.69	1.15	0.75	0.48	2.77
Matching Force Grip (kg)	259	24	235					
Low	59	8	51	<=4.01	1.00			
Medium	94	8	86	>4.01 & <= 5.53	0.59	0.32	0.21	1.68
High	106	8	98	>5.53	0.52	0.22	0.18	1.47
Matching Force Pinch (kg)	298	22	276					
Low	85	10	75	<=2.1	1.00			
Medium	132	5	127	>2.1 & <=2.24	0.30	**0.03**	0.10	0.90
High	81	7	74	>2.24	0.71	**0.51**	0.26	1.96
POSTURE & COMPOSITE MEASURES								
Hand Posture (0 to 5)	387	33	354					
Low	150	11	139	<=2.62	1.00			
Medium	89	11	78	>2.62 & <=3.83	1.78	**0.20**	0.74	4.30
High	148	11	137	>3.83	1.01	0.97	0.43	2.42
HAL TLV Score	370	31	339					
Low	150	11	139	<=0.5	1.00			
Medium	113	10	103	>0.5 & <=0.67	1.23	0.65	0.50	3.00
High	107	10	97	>0.67	1.30	0.56	0.53	3.19
HAL TLV Score (HAL Scale)	370	31	339					
Low	176	13	163	<=0.56	1.00			
Medium	146	13	133	>0.56 & <=0.78	1.23	0.62	0.55	2.73
High	48	5	43	>0.78	1.46	0.50	0.49	4.31
HAL TLV Score (Video- Total Reps)	348	29	319					
Low	128	10	118	<=0.56	1.00			
Medium	148	10	138	>0.56 & <=0.78	0.86	0.74	0.34	2.12
High	72	9	63	>0.78	1.69	0.28	0.65	4.36
HAL TLV Score(Video- Heavy Pinch & Grip)	380	31	349					
Low	283	22	261	<=0.56	1.00			
Medium	64	5	59	>0.56 & <=0.78	1.01	0.99	0.37	2.76
High	33	4	29	>0.78	1.64	0.39	0.53	5.08
Strain Index Score (case cutoff)	209	20	189					
Low	85	7	78	<=19.5	1.00			
Medium	76	7	69	>19.5 & <=53.16	1.13	0.83	0.38	3.38
High	48	6	42	>53.16	1.59	0.43	0.50	5.04
Strain Index Score	209	20	189					
Low	49	3	46	<=7	1.00			
High	160	17	143	>7	1.82	0.36	0.51	6.50

Figure 1a. Right side: Odds ratios for various force measures including the VAS, tool weight, and the percent time in heavy pinch.

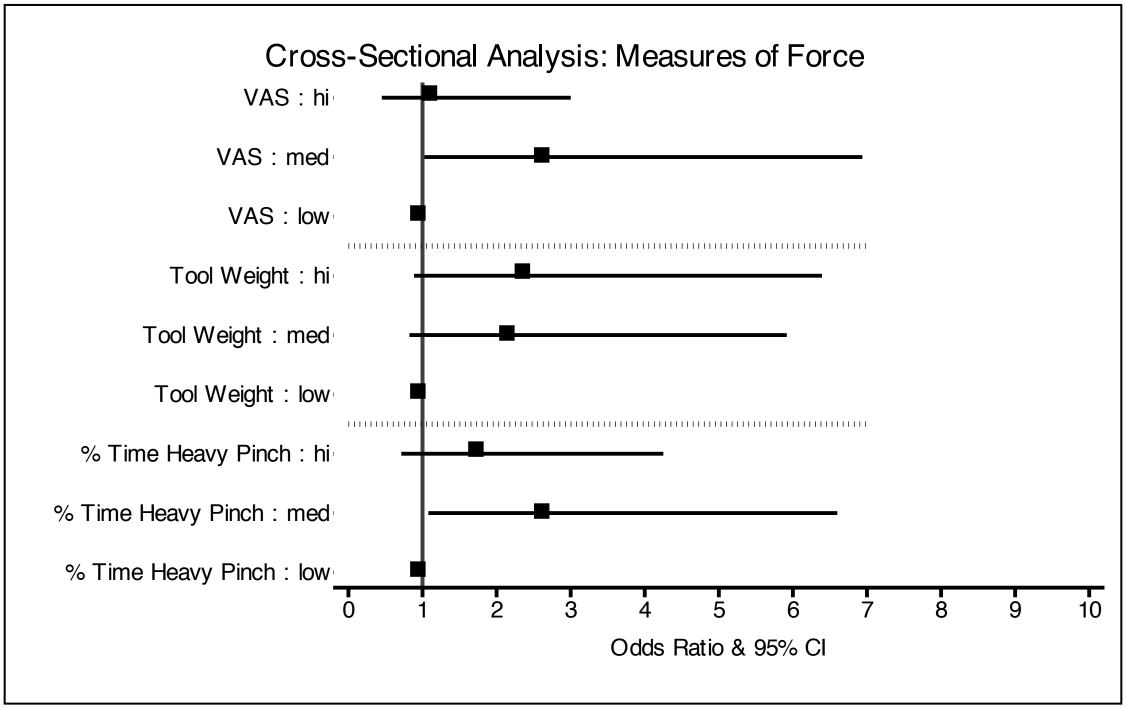


Figure 1b. Right side: Odds ratios for the percent time in light or heavy pinch and/or grip including: heavy pinch, heavy pinch or grip, all pinch or grip, and light pinch or grip.

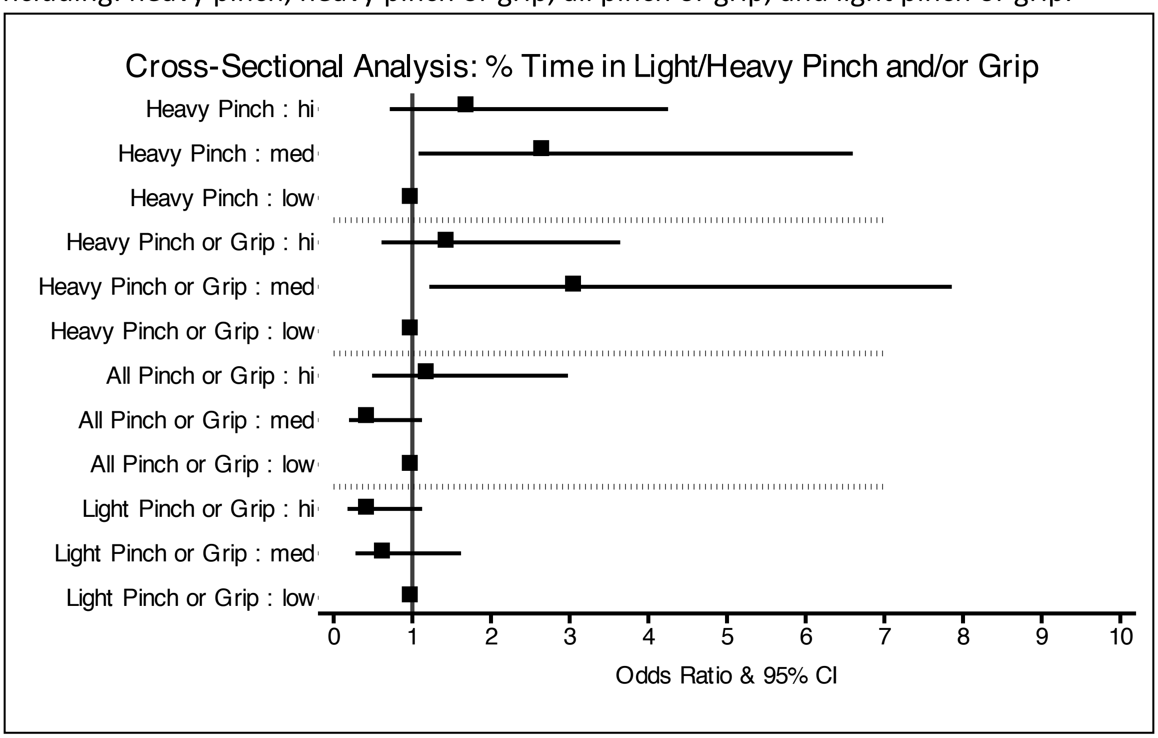


Figure 2a. Right side: Odds ratios for various measures of repetition including: observer-rated HAL scale, reps/min in heavy pinch or grip, and total reps/min (all hand postures).

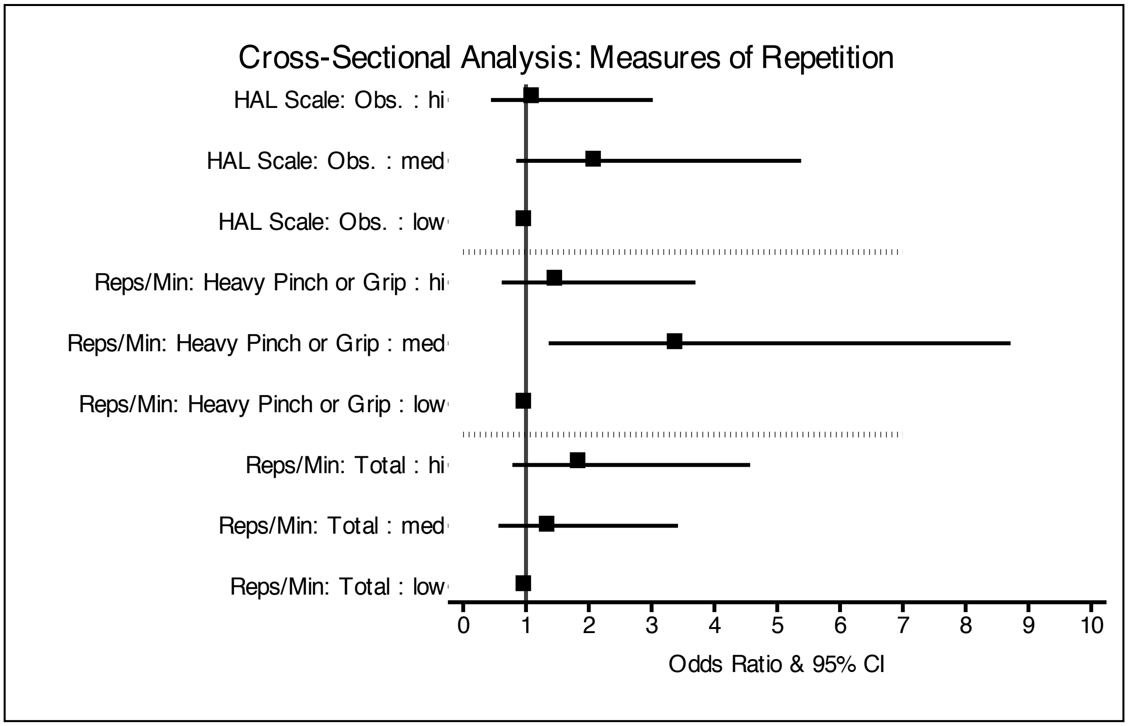


Figure 2b. Right Side: Odds ratios for repetition rate in various hand postures including: heavy pinch, heavy pinch or grip, total/ all, and light pinch.

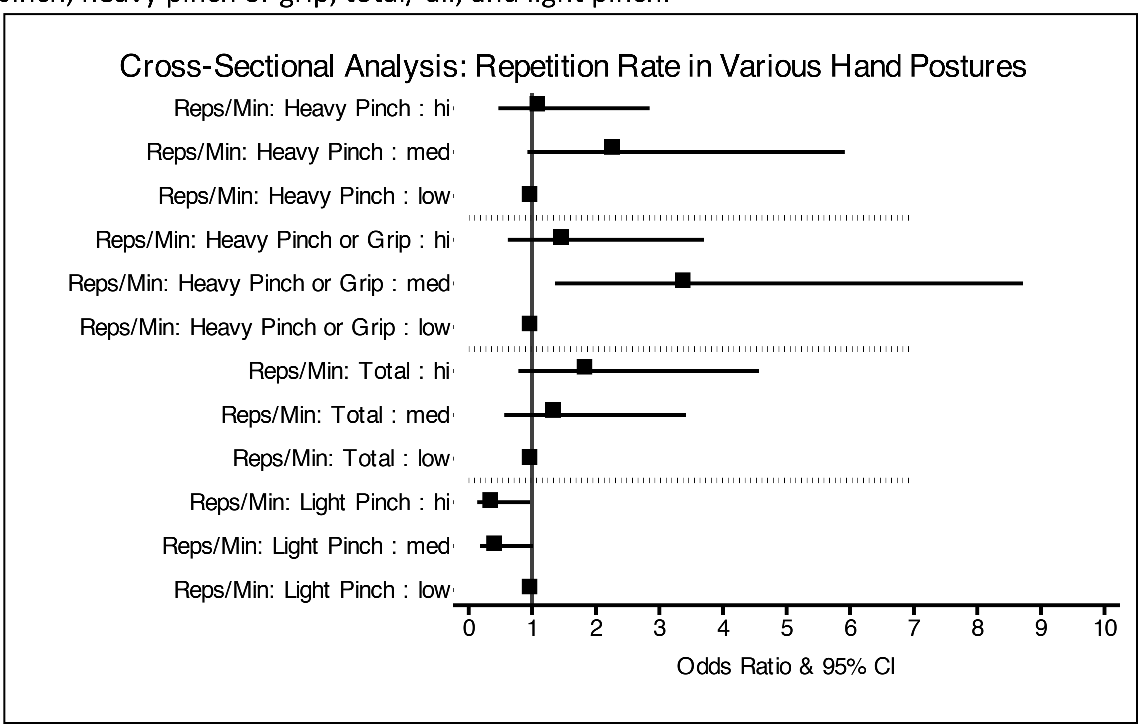


Figure 3a. Right side: Odds ratios for the percent time in heavy pinch or grip, controlling for various measures of repetition including: HAL scale, heavy pinch or grip, and total.

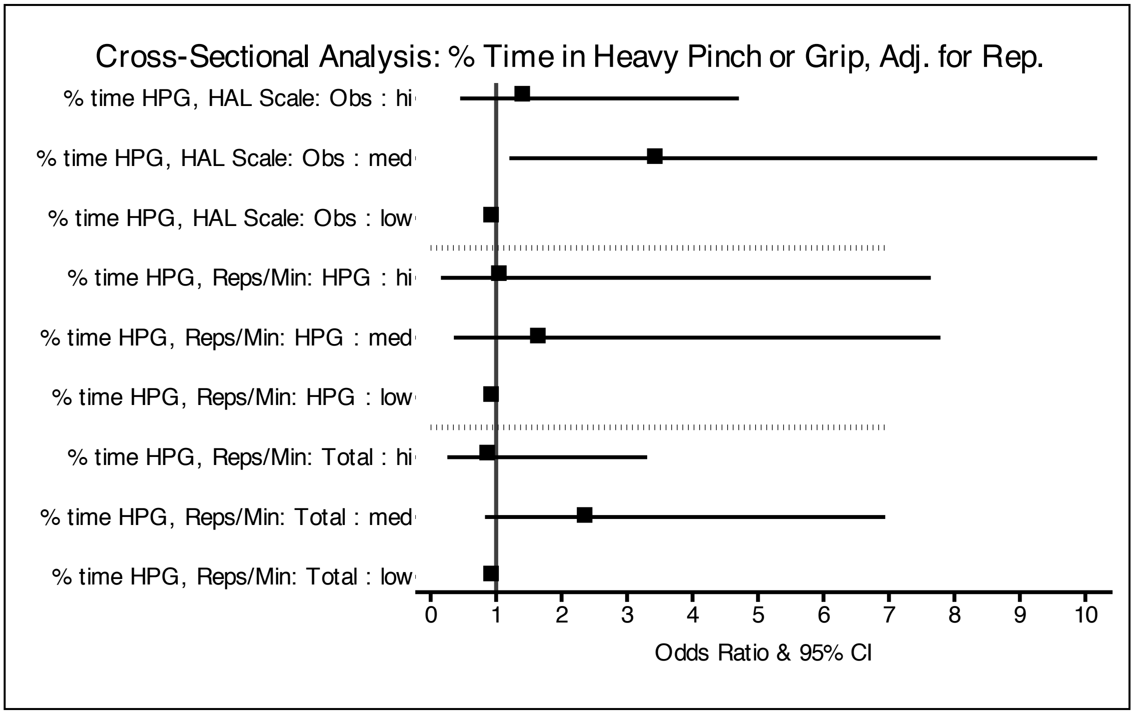


Figure 3b. Right Side: Odds ratios for the percent time in heavy pinch, controlling for various measures of repetition including: HAL scale, heavy pinch or grip, and total.

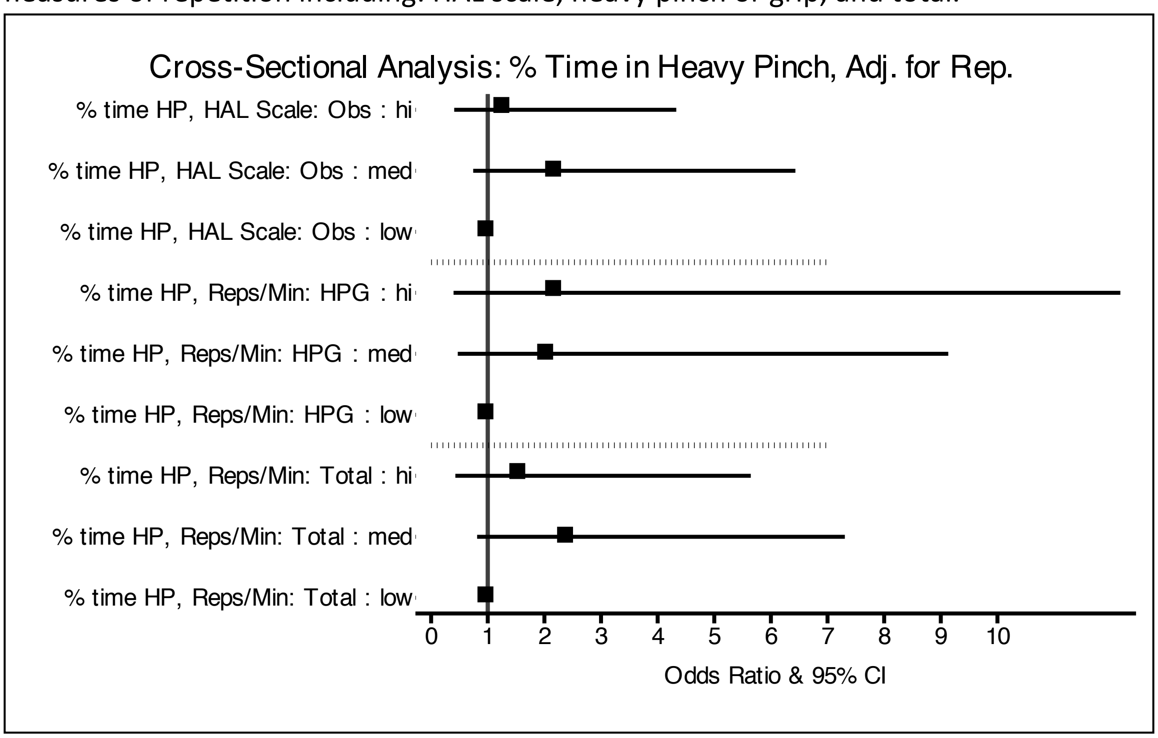
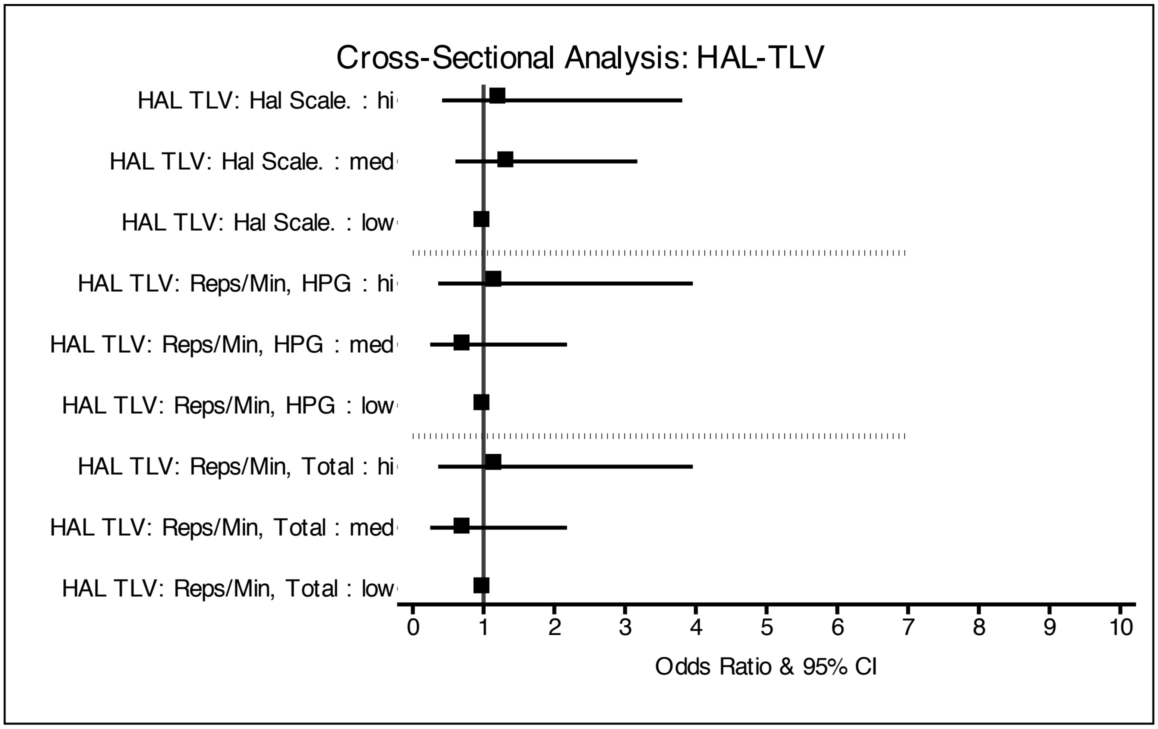


Figure 4. Right side: Odds ratios for the composite measure of force & repetition, using the HAL-TLV with different methods for quantifying repetition including: HAL scale, reps/min in heavy pinch or grip, and total reps/min (all hand postures).



Prospective Analysis

Introduction

Wrist flexor and extensor tendinopathies are common work related distal upper extremity disorders. Tendons connect muscles to bones and repeated forceful loading can lead to inflammation, microtears, and 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. (1986) found that high hand forces, that is, forces greater than 44.1N (4kg) for power grip and greater than 8.9N (1kg) for pinch grip posed a significant risk on hand and wrist musculoskeletal disorders such as tendinosis. Other studies have found that 'high hand force' is an independent risk factor of hand and wrist tendinosis (Armstrong et al., 1987; Leclerc et al., 2001; Silverstein et al., 1986; Thomsen et al., 2007). Independently, repetitive motions, defined by tasks with wrist or hand exertions repeating more frequently than every 30 seconds, are associated with increased prevalence of distal upper extremity (hand and wrist) discomfort and tendinosis with an odds ratio ranging from 1.17 to 3.23 (Latko, 1999; Silverstein et al., 1987; Silverstein et al., 1986).

While individual physical risk factors have been shown to be associated to UEMSDs, numerous studies also indicate that combinations of these same risk factors are related to even higher risk. Silverstein et al. (1987) found that the odds ratio for carpal tunnel syndrome in highly repetitive jobs compared to low repetition jobs, regardless of force, was 5.5. The odds ratio increased to 15.5 for jobs with combined exposures to high force and high repetition when compared to jobs with low force and low repetition. Knox and Moore found that the odds ratio could be as high as 50 when exposure to high force, repetition and awkward posture coexisted in a job (Franzblau et al., 2005; Knox & Moore, 2001). Several authors have proposed combining individual risk factors in formulas or indices (e.g., ACGIH Hand Activity Level Threshold Limit Value, Strain Index) that may improve the prediction of UEMSDs over individual physical risk factors. However, these indices have been tested in very few prospective studies for wrist tendinosis (Knox & Moore, 2001).

Additionally, although crude relationships between repetition, force, posture and musculoskeletal disorders are known, little is known about the dose-response relationship between these individual risk factors and UEMSDs, or their combined effect. In fact, there have not been any rigorous prospective studies to date that have assessed casual factors for wrist tendinosis. By identifying a clear relationship of causal factors, and a threshold of individual and/or combinations of physical risk factors that cause wrist tendiosis, guidelines and policies can be developed to prevent them from occurring in the workplace.

Methods of Statistical Analysis

Survival analysis, for those participants who were not diagnosed with right wrist tendinosis at baseline, was performed using the Cox Proportional Hazards Model with robust confidence intervals and was used for all univariate and subsequent multivariate analyses. All models included adjustment for age and gender. Repetition and force specific exposure variables were divided into tertiles based on equal cases in high, medium, and low exposure groups. The ACGIH-TLV for hand activity level was applied using standard cutoffs of 0.56 and 0.78, and the strain index was divided into a high and low group based on standard cutoffs of 3 and 7, and an equal number of cases in each group. Exposure variables related to the outcome with a p<0.2 were analyzed further in a multivariate model. Potential confounders were included in each multivariate model and sequentially removed and replaced. Next, variables correlated with the primary exposure variable of interest (r>0.3) were added into the model and then sequentially removed and replaced. Variables that changed the hazard ratio more than ten percent were retained in the final model. Model comparisons were based on multivariate models that were the best predictors of right wrist tendinosis.

Results

Incidence Rates

There was a total of 481.4 years of person time in the study. Four hundred and thirteen individuals had follow-up data for up to 28 months and a minimum of 2.3 months (Table 1).

During the 28 months of follow up, 175 workers reported pain in the right hand or wrist that exceeded our apriori criteria (Table 2). There were 26 incident cases of right wrist tendinosis, based on symptom and physical examination criteria, leading to a calculated incident rate of 5.4 cases per 100 person-years. There were approximately twice as many wrist extensor tendinosis (n=22) cases than wrist flexor tendinosis (n=11) cases on the right side, with some individuals having multiple specific wrist tendinosis diagnoses at one time (these subjects were counted as just one case in the analyses). Flexor carpi radialis tendinosis was the most prevalent wrist flexor tendinosis diagnosed (n=7) with an incidence rate of 1.4 cases per 100 person-years. Tendinosis of the 1st dorsal compartment (de Quervains Syndrome) had the highest overall incidence at 2.7 cases per 100 person-years (n=13).

The incidence rate of right wrist tendinosis (Table 3) among women (IR=11.3) was much higher than for men (IR=2.2), and was slightly higher for those over 40 years of age (IR=6.5) than those under 40 years of age (IR= 4.4). Those of Hispanic descent (IR=5.5) had a higher incident rate of right wrist tendinosis than those of all other ethnicities (IR= 2.5). Those with a medical condition including diabetes, gout, lupus, thyroid disease, or rheumatoid arthritis (IR=11.5) had a substantially higher incidence rate of right wrist tendinosis than those who did not (IR=4.9). Those who rated their health as poor at baseline (IR=6.0) had slightly higher incidence rate compared to those who rated their health as fair or better (IR=4.5). Day shift workers(IR=7.8) had a substantially higher incidence of than those on other shifts (IR=0.62), yet those with low job-strain (IR=4.6) and low iso-strain (IR=4.7) indices had similar incidence rates to those with high job-strain(IR=5.2) or iso-strain indices (IR=5.3). Those who had worked at their current company for 2 to 5 years (IR=7.1) had higher incidence rates than those with less than 2 years (IR=5.5) or greater than 5 years (IR=4.8). Those who reported being unsatisfied with their job had lower incidence rates (IR=2.6) than those who reported being satisfied (IR=5.2). The incidence rate for the chair manufacturing plant (IR=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. The overall incidence rate for right wrist tendinosis was 5.4 per 100 person-years.

Univariate Analysis.

Demographic & Work Psychosocial Variables. Being female increased the risk (HR = 4.8; 95% CI: 2.01-11.45) of developing right wrist tendinosis (Table 3) as did being on the day shift (HR =11.91; 95% CI: 1.59-89.35;), being Hispanic (HR = 2.44; 95% CI: 0.53-11.37) or having a medical condition (HR = 2.38; 95% CI: 0.88-6.43), all of which were included in the preliminary multivariate model. Based on a high correlation value, annual income was also initially included in multivariate models. Though not significant enough to include in the model, a healthy worker effect was seen with those who worked greater than 5 years at their current job having a decreased risk of right wrist tendinosis (HR=0.86; 95%CI 0.31-2.36) than those who worked less than 5 years.

Force Measures. The Visual Analog Scale for hand fatigue, a self-report measure, had medium and high group hazard ratios of 1.81 (95% CI: 0.63-5.19) and 1.87 (95% CI: 0.63-5.52). A direct measure of force represented by tool weight was protective for both medium (HR=0.06; 95%CI: 0.01-0.28) and high (HR=0.47; 95%CI: 0.18-1.21) exposure groups; however, this should be interpreted with caution because the case sample sizes are so low (n=2 and 7). The normalized peak force, representing normalized force matching values from both pinch and grip postures, was associated with no risk increase for the medium (HR= 0.82; 95%CI: 0.32-2.08) exposure group but an increased risk for the high (HR= 4.68; 95%CI: 1.71-12.77) exposure groups with the cutoffs being 1.5 and 4.8, respectively. Video based assessments of percent time spent in heavy pinch had a hazard ratio of 1.87(95% CI: 0.74-4.72) and 1.7(95% CI: 0.6-4.83) for medium and high groups and the percent time spent in heavy grip had a hazard ratio of 1.01(95% CI: 0.34-2.96) and 0.45(95% CI: 0.16-1.25) for medium and high groups.

Repetition Measures. The HAL Scale, an observer-rated repetition measure, was slightly protective with a hazard ratio of 0.78 (CI: 0.21-2.87) and 0.81 (CI=0.28-2.34) for medium and high groups. Speed of work, another observer-rated measure of repetition, had similar yet more significant findings for medium (HR= 0.22; 95%CI: 0.05-1.00) and high (HR=0.45; 95%CI: 0.18-1.14) exposure groups. The video analysis method quantifying repetition rate while in heavy grip showed similar trends with medium (HR= 0.81; 95% CI:0.27-2.39) and high (HR= 0.43; 95%CI: 0.16-1.17) exposure groups having reduced risk for right wrist tendinosis. However, repetition rate quantified for medium and heavy exposure groups while performing a light pinch (medium group HR=5.63; 95%CI: 2.25-14.14; high group HR= 1.47; 95%CI: 0.56-3.87) and, to a lesser extent, a heavy pinch (Table 4) indicated more risk of diagnosis. The hazard ratio for total repetition rate, including number of exertions per minute across all five core hand postures, had medium and high group hazard ratios of 1.4 (CI: 0.57-3.43) and 0.93 (CI: 0.36-2.41), respectively.

Composite Measures. Posture, as assessed via an observer-rated scale, showed a higher risk for the medium exposure (HR= 3.04; 95%CI: 1.09-8.48) group than high exposure (HR= 0.95 ; 95%CI: 0.36-2.5) group. The ACGIH-TLV for Hand Activity Level calculated using the observer-rated HAL Scale had medium and high group hazard ratios of 2.24 (95%CI: 0.86-5.85) and 3.99 (95% CI: 1.4-11.33). The ACGIH-TLV score calculated using the repetition rate while in heavy pinch or grip had hazard ratios of 4.47(95% CI: 2.14-9.37) and 2.21(95% CI: 1.52-11.67), and was similar when calculated using the repetition rate in all hand postures. The Strain Index, when split into two groups, had a hazard ratio of 4.69 (95% CI: 0.67-32.56).

Multivariate Analysis

The various methods used to quantify force were compared in multivariate models that included age and gender (Figure 1a). Self-report measure of force using the VAS for hand fatigue showed an increase in 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. 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. However, both models had only 21 cases versus the models for normalized peak force and the percent time in heavy pinch which had 26 cases. Direct measurement using normalized peak force from matching pinch and grip measurements showed no change in risk in the medium exposure (HR=0.93; 95% CI: 0.35-2.41) group but a significantly higher increase in risk in the high exposure (HR=3.26; 95% CI: 1.15-9.3) group. The percent time in heavy pinch, as quantified using video analysis, showed an increase in risk, though not significant, of 1.6 (95% CI: 0.6-4.24) and 1.81 (95%CI: 0.66-5.0) for medium and high exposure groups, respectively.

The model for percent time in heavy pinch was compared to the percent time in other hand postures (Figure 1b). The hazard ratios for the percent time in heavy pinch or grip were 1.51 (95% CI: 0.57-3.99) and 1.28 (95% CI:0.47-3.5) for medium and high groups, respectively. For the percent time in any pinch or grip, the hazard ratios were protective for medium 0.83(95% CI: 0.33-2.07) and high 0.45(95% CI:0.16-1.29) groups.

Multivariate models, controlling for age and gender, comparing different methods for quantifying repetition are shown in Figure 2a. The observer-rated HAL scale hazard ratios for medium and high groups were 0.97 (95%CI: 0.28-3.45) and 1.02(95%CI: 0.41- 2.54). Hazard ratios for speed of work were protective for medium (HR=0.22; 95% CI: 0.05-0.98) and high (HR=0.67; 95% CI: 0.27-1.65) exposure groups. For video analyzed repetition rate during any grip, the hazard ratios were slightly protective yet not significant for either the medium (HR=0.95; 95%CI: 0.36-2.48) or high (HR=0.77; 95%CI: 0.28-2.13) exposure groups. The repetition rate during any pinch had hazard ratios of 1.67 (95%CI: 0.63-4.38) and 0.76 (95%CI: 0.27-2.09) for medium and high exposure groups, respectively.

The repetition rate of other hand postures and combinations of hand postures are presented in Figure 2b. The hazard ratios for medium and high exposure groups while in heavy pinch were 1.04 (95% CI: 0.39-2.79) and 1.49 (95%CI: 0.54-4.12). Repetition rate while in heavy 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. When the repetition rate for heavy pinch and grip were combined, the hazard ratios increased to 1.47 (95% CI: 0.74-4.0) for both medium and high exposure groups. When the repetition rate for all five hand postures, including light and heavy pinch or grip and no load, was analyzed, the hazard ratios were more protective for medium (HR=0.95; 95%CI: 0.37-2.48) and high (HR=0.69; 95%CI: 0.26-1.9) exposure groups.

When adjusting the model of percent time spent in heavy pinch for repetition as measured by observer-rated HAL scale, the hazard ratios 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 3a). The results were similar when adjusting for the repetition rate in heavy pinch or grip or all postures, with the hazard ratios being 2.75(95%CI: 0.33-23.17) and 4.13(95%CI: 0.35-49.1) during heavy pinch or grip, and 2.07 (95%CI: .76-5.66) and 5.01 (95%CI: 1.27-19.79) during all hand postures, for medium and high exposure groups, respectively.

When adjusting models for different measures of repetition with the percent time spent in heavy pinch, the hazard ratios decreased substantially and were primarily protective (Figure 3b).

Three measures of repetition were used to calculate three different ACGIH-TLV HAL scores and were assessed in a multivariate model including age and gender (Figure 4). Hazard ratios 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 groups. When using the video based repetition rate for heavy pinch or grip posture and all hand postures, the hazard ratios were 3.95 (95% CI:1.52-10.26) and 2.8 (0.8-9.87) for the medium and high groups, respectively.

The strain index was also assessed in a multivariate model including age and gender and had a hazard ratio of 4.69(95% CI: 0.67-32.56). The analysis included 197 subjects and 14 cases and the two comparison groups were based on a cutoff value of 7. When the same analysis was performed basing the cutoff (40.5) on an equal number of cases in each group, the hazard ratio was similar (Table 4).

Discussion

Non-Occupational and Psychosocial Factors. Being female was a significant predictor of wrist tendinosis, although this was likely driven in part by the high number of women in jobs with tasks that require high pinch force such as sewing. 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. Psychosocial factors have had inconsistent associations with upper extremity musculoskeletal disorders (Leclerc et al., 2001; Roquelaure et al., 2001) and job control as measured by demand, control, and strain through the Job Content Questionnaire was not a significant predictor in this study. Additionally, shift, ethnicity, BMI, job satisfaction, and hand dominance had very few cases in comparison groups limiting the precision of the estimates and an ability to make inferences from the findings.

Force Measures. An interesting finding was the similar hazard ratios for medium and high exposure groups for the percent time in heavy pinch and the self-reported Visual Analog Scale for hand fatigue. This relationship was not seen at baseline in the high exposure groups, and may indicate the eventual inability for those with wrist tendinosis to remain in high exposure jobs. At the single task level the correlation between these two exposure variables was moderate (r=0.35); this may explain some of the similarity. Additionally, the direct measure of normalized peak force, which was derived from force matching in pinch and grip, was strongly associated with right wrist tendinosis in the high exposure group. Again, this relationship was not seen in the cross-sectional analysis at baseline. The lack of a relationship in the cross-sectional data may be due to a healthy worker effect, where workers with an injury may have already self-selected out (or been placed on modified duty) of the high exposure groups by changing tasks or jobs. Unexpectedly, a higher object-tool weight showed a protective relationship with right wrist tendinosis. However, the smaller sample size again reduces the precision of this estimate and makes it difficult to draw major conclusions. It may be that a heavier tool weight increases the amount of time spent in grip versus pinch, which may reduce exposure to heavy pinch.

The time spent in heavy pinch was the most significant predictor of wrist tendinosis, and the relationship followed a dose response pattern. The risk of developing wrist tendinosis decreased as more time was spent in power grip even if the grip was forceful or in light pinch or grip. This strong association with heavy pinch may be associated with the higher incidence of tendinosis of the abductor pollicis longus (deQuervains tenosynovitis), a tendon that is very active during pinch. When adjusting time in heavy pinch with different measures of repetition (Figure 3a), the hazard ratio increased nearly two fold for both the medium and high groups indicating that high pinch force alone is an important predictor of right wrist tendinosis. This appears a robust relationship given that the pattern is preserved after adjusting for different measures of repetition (Figure 3a).

Repetition Measures. Three different methods of quantifying repetition were assessed in this study: observer-rated scales of the HAL repetition score and speed of work, and video based quantification of repetition rate in heavy pinch and grip, and all hand postures (Figure 2a). Figure 2b also compares hazard ratios for repetition rates in heavy pinch alone, heavy grip alone, any grip, and any pinch. Regardless of the method used, repetition showed no predictive value for identifying cases of right wrist tendinosis. After the models were adjusted for force, measured by the percent time spent in heavy pinch, a protective pattern for repetition emerged (Figure 3b). This was a surprising finding given the prior risks associated with repetition identified in other studies. 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 homogeneous but covered a broad range as indicated by the upper and lower tertile range of 67 and 43 total repetitions per minute.

Composite Measures. The ACGIH-TLV for Hand Activity Level and Strain Index are tools used by safety professionals in the workplace to quantify job exposure to more than one type of risk factor such as force, repetition, and posture. The ACGIH-TLV for Hand Activity Level (HAL TLV) is a relatively simple tool that quantifies exposure to force and repetition for mono-task jobs. In this study, a time weighted average (TWA) methodology applied to the HAL-TLV account for multi-task jobs. This TWA TLV was a good predictor of wrist tendinosis, with a 2.5 to 4 fold increase in hazard for developing wrist tendinosis for those with a moderate (>0.56) or high (>0.78) TLV score. There was no difference in hazard ratio for the moderate or high score indicating a possible threshold effect at the moderate level. The value of the HAL-TLV was robust as indicated by the similar findings when using three different methods for representing repetition when calculating HAL for TLV scores. This may be important for practitioners since the observer-rated field assessment of the HAL repetition scale is much quicker and easier to apply than the video analysis method.

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 TLV for HAL. The hazard ratio for the strain index was increased with scores greater than 7, a cutoff point commonly used in the literature. While using 7 as a cutoff point nearly perfectly predicted all those who developed wrist tendinosis (13 of 14) 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 greater than 7. Unfortunately, the smaller number of subjects with the full strain index data makes any inferences difficult.

Challenges & Limitations. While the study design had important strengths, such as the prospective design and the detailed and blinded assessment of exposures and outcomes, some limitations should be noted. Self-report worker estimates of weekly time spent on each task were important multipliers for calculating the time-weighted average exposures. However, estimation errors would likely be non-differential and bias the findings toward the null. Worker task duration estimations were assessed on different occasions throughout the study. An evaluation of the differences in self-report values at different time points may shed some light on the reliability of their estimates.

In addition, the number of cases of right wrist tendinosis was relatively small so it is possible that some of the exposure variables that were not strongly associated with the outcome were a result of inadequate power. There were seven individuals who reported having non-work related pain that met the criteria for triggering a physical exam but were not examined. It is possible that some of these individuals may have been diagnosed with wrist tendinosis. However, out of 154 subjects undergoing a physical exam on the hand and wrist, only 26 were diagnosed with wrist tendinosis. If the workers with non-work related pain had been examined, it is likely that they would have yielded only 1 to 2 additional cases, a number not likely to change the findings of this study.

In conclusion, the percent time spent in heavy pinch is an important risk factor for the occurrence of wrist tendinosis. Although these findings were specific to the right hand, it is reasonable to assume similar conclusions regarding the left hand. The exposure assessment method used to quantify ones exposure to heavy pinch was unique in that it quantified the amount of time spent over a threshold value of 1kg 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 (Bao et al., 2006). Additionally, previous cross sectional studies have indicated an association with all types of hand force (grip and pinch), repetition, and wrist tendinosis. This study highlights the singular importance of heavy 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 the only known prospective study using individualized exposure assessment methods and looking at wrist tendinosis in the work place.

Tables & Figures

Table 1: Person time summary.

Person Time Summary	Site 1 n=48	Site 2 n=32	Site 3 n=160	Site 4 n=173	Total n=413
Total Time (years)	**94.77**	**41.65**	**192.38**	**152.67**	**481.40**
Total Time (months)	1,137.28	499.75	2,308.60	1,831.98	5,776.80
Average Person Time (months)	236.93	156.17	14.43	10.59	139.89
Minimum Person Time (months)	3.65	4.01	3.94	2.23	2.23
Maximum Person Time (months)	28	25.49	28.75	13.83	28.75

Table 2: Incidence of wrist tendinosis.

Prospective Wrist Tendinosis Summary	28 MONTH FOLLOW UP N=413						
	N	Left Side	Right Side	Either Side	Left Side Incidence/ 100 person-years	Right Side Incidence / 100 person-years	Either Side Incidence / 100 person-years
Hand/Wrist Symptoms	413	158	175	152			
Number of Physical Exams	413	133	137				
Total Hand/Wrist Tendonitis Disorders/Cases	**413**	**17**	**26**	**31**	**3.73**	**5.40**	**5.84**
Flexor Tendonitis	**413**	**7**	**11**	**16**	**1.42**	**2.24**	**3.27**
Flexor Carpi Radialis Tendonitis	413	3	7	9	0.61	1.42	0.20
Flexor Carpi Ulnaris Tendonitis	413	2	0	2	0.40	0.00	0.40
Flexor Digitorum Tendonitis	413	2	5	6	0.40	1.01	1.21
Trigger Finger	413	1	2	3	0.20	0.40	0.61
Extensor Tendonitis	**413**	**15**	**22**	**26**	**3.11**	**4.56**	**4.80**
Dorsal Compartment 1	413	12	13	16	2.47	2.68	2.89
Dorsal Compartment 2	413	3	2	3	0.61	0.40	0.61
Dorsal Compartment 3	413	3	6	6	0.61	1.23	1.23
Dorsal Compartment 4	413	2	6	6	0.41	1.21	1.01
Dorsal Compartment 5	413	0	0	0	0.00	0.00	0.00
Dorsal Compartment 6	413	5	4	7	1.02	0.81	1.43
Intersection Syndrome	413	0	0	0	0.00	0.00	0.00

Table 3: Univariate analysis: demographics and work psychosocial variables.

Participant Demographics: Prospective Cohort Right Wrist Tendinosis (N=413)	N (Right Side Analysis)	Right Side Cases	Controls	Incident Rate	HR	p-value	Lower CI	Upper CI
Gender	**413**	**26**	**387**					
Male	262	7	255	2.23	1.00			
Female	151	19	132	11.34	4.80	0.00	2.01	11.45
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	0.27	0.72	3.31
Ethnicity	**398**	**23**	**398**					
Non-Hispanic	53	2	51	2.48	1.00			
Hispanic	345	21	324	5.45	2.44	0.26	0.53	11.37
Body Mass Index	**406**	**26**	**380**					
Body Mass Index (<30)	265	18	247	5.77	1.00			
Body Mass Index (>30: obese)	141	8	133	4.95	0.89	0.79	0.39	2.07
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	369	21	348	4.91	1.00			
Medical Condition	39	5	34	11.50	2.38	0.09	0.88	6.43
No Gout, RA, Lupus	394	24	370	5.28	1.00			
Gout, RA, Lupus	12	2	10	14.19	2.71	0.20	0.60	12.29
No Diabetes	380	23	357	5.23	1.00			
Diabetes	27	3	24	10.28	2.04	0.26	0.59	7.04
No Hyper/Hypothyroidism	401	24	377	5.18	1.00			
Hyper/Hypothyroidism	4	1	3	27.52	5.59	0.10	0.72	43.52
Not currently Pregnant	75	12	63	13.92	1.00			
Currently Pregnant	1	0	1	0.00	0.00	0.00	0.00	0.00
No Birth Control Pill	71	12	59	14.52	1.00			
Birth Control Pill	5	0	5	0.00	0.00	0.00	0.00	0.00
No Medication*	140	12	128	6.65	1.00			
Medication*	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	0.81	0.29	2.64
Activity	**398**	**24**	**374**					
< 1 hour/week	181	11	170	5.22	1.00			
>=1 hour/week	217	13	204	5.14	0.99	0.99	0.45	2.20
Overall Health Status	**400**	**23**	**377**					
Poor	115	8	107	6.02	1.00			
Fair or better	285	15	270	4.47	0.76	0.54	0.33	1.79
Educational Level	**406**	**23**	**383**					
Some or no Highschool	289	16	273	5.12	1.00			
Highschool graduate or higher	117	7	110	4.36	0.81	0.69	0.28	2.30
Annual Income	**279**	**14**	**265**					
<30k per year	144	8	136	5.05	1.00			
>= 30k per year	135	6	129	4.02	0.75	0.61	0.25	2.29

Shift	**405**	**25**	**380**					
Swing/Night/Rotating Shift	142	1	141	0.62	1.00			
Day Shift	263	24	239	7.80	11.91	0.02	1.59	89.35
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	0.83	0.46	2.64
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	0.80	0.40	3.35
Years at Job	**413**	**26**	**387**					
<2 years	85	5	80	5.49	1.00			
>=2 years & < 5 Years	88	7	81	7.08	*1.22*	*0.73*	0.39	*3.80*
> 5 years	240	14	226	4.80	*0.86*	*0.77*	0.31	*2.36*
Job Satisfaction	**394**	**23**	**371**					
Unsatisfied	31	1	30	2.59	1.00			
Satisfied	363	22	341	5.21	2.02	0.50	0.26	15.61
Job Site	**413**	**26**	**387**					
Site 1	48	0	48	0.00	.			
Site 2	32	6	26	14.41	1.00			
Site 3	160	15	145	7.80	0.62	0.41	0.20	1.94
Site 4	173	5	168	3.28	0.32	0.14	0.07	1.45
H/W Tendinosis	**413**	**26**	**387**	**5.40**				

Table 4: Univariate Analysis: Exposure Variables

EXPOSURE VARIABLES: TIME WEIGHTED AVERAGE	N (TOTAL)	Cases	Controls	Cutoff Values	HR	p-value	Lower CI	Upper CI
REPETITION MEASURES								
Hand Activity Level (HAL) Scale	**354**	**24**	**330**					
Low	139	13	126	<=3.33	1.00			
Medium	45	3	42	>3.33 & <=4.41	0.78	0.70	0.21	2.87
High	170	8	162	>4.41	0.81	0.70	0.28	2.34
Efforts/ Min	**156**	**13**	**143**					
Low	64	12	52	<=13.33	1.00			
High	92	1	91	>13.33	0.05	**0.01**	0.01	0.40
Speed of Activity	**354**	**24**	**330**					
Low	108	14	94	<=2.67	1.00			
Medium	68	2	66	>2.67 & <=3.06	0.22	**0.05**	0.05	1.00
High	178	8	170	>3.06	0.45	**0.09**	0.18	1.14
Reps/min: % Time No Load	**388**	**26**	**362**					
Low	130	9	121	<=1.93	1.00			
Medium	120	9	111	>1.93 & <=13.05	1.12	0.81	0.44	2.89
High	138	8	130	>13.05	1.08	0.87	0.40	2.93
Reps/min: % Time Light Pinch	**387**	**26**	**361**					
Low	237	9	228	<=13.91	1.00			
Medium	31	9	22	>13.91 & <=24.02	5.63	**0.00**	2.25	14.14
High	119	8	111	>24.02	1.47	0.44	0.56	3.87
Reps/min: % Time Heavy Pinch	**389**	**26**	**363**					
Low	122	9	113	<=1.59	1.00			
Medium	127	9	118	>1.59 & <=19.04	1.00	1.00	0.39	2.56
High	140	8	132	>19.04	1.43	0.48	0.53	3.89
Reps/min: % Time Light Grip	**381**	**26**	**355**					
Low	95	9	86	<=0.24	1.00			
Medium	104	9	95	>0.24 & <=2.77	0.85	0.74	0.33	2.20
High	182	8	174	>2.77	0.60	0.31	0.23	1.61
Reps/min: % Time Heavy Grip	**360**	**21**	**339**					
Low	91	9	82	<=0.31	1.00			
Medium	62	5	57	>0.31 & <=0.96	0.81	0.70	0.27	2.39
High	207	7	200	>0.96	0.43	**0.10**	0.16	1.17
Reps/min: % Time Heavy Pinch or Grip	**389**	**26**	**363**					
Low	134	9	125	<=4.52	1.00			
Medium	96	9	87	>4.52 & <=19.2	1.40	0.49	0.54	3.59
High	159	8	151	>19.2	1.29	0.62	0.47	3.49
Reps/min: % Time Any Pinch	**389**	**26**	**363**					
Low	152	9	143	<=33	1.00			
Medium	95	9	86	>33 & <=40.02	2.41	**0.09**	0.88	6.55
High	142	8	134	>40.02	1.21	0.70	0.45	3.23
Reps/min: % Time Any Grip	**384**	**26**	**358**					
Low	100	10	90	<=0.55	1.00			
Medium	86	8	78	>0.55 & <= 4.21	0.82	0.69	0.32	2.14
High	198	8	190	>4.21	0.52	**0.19**	0.20	1.37

Reps/min: % Time All Pinch & Grip	**389**	**26**	**363**					
Low	117	9	108	<=38.88	1.00			
Medium	97	9	88	>38.88 & <=47.24	1.40	0.46	0.57	3.43
High	175	8	167	>47.24	0.93	0.89	0.36	2.41
FORCE MEASURES								
Rate of Perceived Exertion	**336**	**19**	**317**					
Low	125	9	116	<=2.67	1.00			
Medium	83	6	77	>2.67 & <= 3.66	1.12	0.84	0.39	3.18
High	128	4	124	>3.66	0.58	0.36	0.18	1.88
Visual Analog Scale	**345**	**21**	**324**					
Low	149	7	142	<=3.43	1.00			
Medium	80	7	73	>3.43 & <=5.14	1.81	0.27	0.63	5.19
High	116	7	109	>5.14	1.87	0.26	0.63	5.52
% Time No Load	**388**	**26**	**362**					
Low	117	9	108	<=4%	1.00			
Medium	124	9	115	>4% & <=27%	1.08	0.88	0.42	2.78
High	147	8	139	>27%	0.86	0.76	0.32	2.30
% Time Light Pinch	**386**	**26**	**360**					
Low	203	9	194	<=22%	1.00			
Medium	74	9	65	>22% & <=46%	1.86	0.24	0.67	5.19
High	109	8	101	>46%	1.20	0.72	0.44	3.24
% Time Heavy Pinch	**388**	**26**	**362**					
Low	154	9	145	<=9%	1.00			
Medium	87	9	78	>9% & <=31%	1.87	**0.19**	0.74	4.72
High	147	8	139	>31%	1.70	0.32	0.60	4.83
% Time Light Grip	**382**	**26**	**356**					
Low	29	9	20	<=1%	1.00			
Medium	144	9	135	>1% & <=7%	0.18	**0.00**	0.07	0.45
High	209	8	201	>7%	0.13	**0.00**	0.05	0.36
% Time Heavy Grip	**360**	**21**	**339**					
Low	99	9	90	<=1%	1.00			
Medium	59	5	54	>1% & <=3%	1.01	0.99	0.34	2.96
High	202	7	195	>3%	0.45	**0.12**	0.16	1.25
% Time Heavy Pinch or Grip	**389**	**26**	**363**					
Low	130	9	121	<=10%	1.00			
Medium	84	9	75	>10% & <32%	1.43	0.47	0.54	3.78
High	175	8	167	>32%	1.02	0.97	0.38	2.73
% Time Any Pinch	**388**	**26**	**362**					
Low	137	9	128	<=52%	1.00			
Medium	115	9	106	>52% & <62%	1.77	0.25	0.67	4.64
High	136	8	128	>62%	1.02	0.97	0.37	2.80
% Time Any Grip	**385**	**26**	**359**					
Low	94	11	83	<=2%	1.00			
Medium	60	7	53	>2% & <9%	0.95	0.91	0.38	2.35
High	231	8	223	>9%	0.34	**0.03**	0.13	0.89
% Time All Pinch & Grip	**389**	**26**	**363**					
Low	89	9	80	<=59%	1.00			
Medium	124	11	113	>59% &	0.95	0.90	0.38	2.34

				<=65%				
High	176	6	170	>65%	0.46	**0.15**	0.16	1.32
Tool Weight (kg)	**325**	**21**	**304**					
Low	63	12	51	<=0.6	1.00			
Medium	175	2	173	>0.6 % <=0.91	0.06	**0.00**	0.01	0.28
High	87	7	80	>0.91	0.47	**0.12**	0.18	1.21
Peak Force Hand (kg)	**308**	**20**	**288**					
Low	96	7	89	<=1.8	1.00			
Medium	150	7	143	> 1.8 & <=4.32	0.88	0.81	0.31	2.50
High	62	6	56	>4.32	1.16	0.81	0.35	3.83
Normalized Peak Force	**360**	**26**	**334**					
Low	140	9	131	<=1.49	1.00			
Medium	192	9	183	>1.49 & <=4.92	0.82	0.67	0.32	2.08
High	28	8	20	>4.92	4.68	**0.00**	1.71	12.77
Matching Grip Force (kg)	**237**	**14**	**223**					
Low	32	*5*	27	<=2.96	1.00			
Medium	36	*5*	31	>2.96 & <=4.55	0.66	0.50	0.20	2.21
High	169	*4*	165	>4.55	0.15	**0.00**	0.04	0.55
Matching Pinch Force (kg)	**276**	**18**	**258**					
Low	127	*6*	121	<=1	1.00			
Medium	97	*6*	91	>1 & <=1.36	0.81	0.73	0.25	2.63
High	52	*6*	46	>1.36	0.99	0.99	0.19	5.01
Posture & Composite Measures								
Hand Posture (0 to 5)	**353**	**24**	**329**					
Low	137	9	128	<=2	1.00			
Medium	41	7	34	>2 & <=3	3.04	**0.03**	1.09	8.48
High	175	8	167	>3	0.95	0.91	0.36	2.50
HAL TLV Score (HAL Scale)	**342**	**24**	**318**					
Low	165	8	157	<=0.56	1.00			
Medium	132	10	122	>0.56 & <=0.78	2.24	**0.10**	0.86	5.85
High	45	6	39	>0.78	3.99	**0.01**	1.40	11.33
HAL TLV Score (Video- Total Reps)	**351**	**25**	**326**					
Low	262	10	252	<=0.56	1.00			
Medium	57	11	46	>0.56 & <=0.78	5.84	**0.00**	2.51	13.62
High	32	4	28	>0.78	4.49	**0.01**	1.41	14.31
HAL TLV Score(Video- Heavy Pinch & Grip)	**351**	**25**	**326**					
Low	262	10	252	<=0.56	1.00			
Medium	57	11	46	>0.56 & <=0.78	5.84	**0.00**	2.51	13.62
High	32	4	28	>0.78	4.49	**0.01**	1.41	14.31
Strain Index Score (case cutoff)	**394**	**28**	**366**					
Low	136	6	130	<=40.5	1.00			
High	61	8	53	>40.5	4.97	**0.00**	1.82	13.58
Strain Index Score	**197**	**14**	**183**					
Low	46	1	45	<=7	1.00			
High	151	13	138	7	4.69	**0.12**	0.67	32.56

Figure 1a. Right Side: Hazard ratios for different measures of Force including self-rated VAS, direct measure tool weight, direct measure normalized peak force, and video analysis % time in heavy pinch.

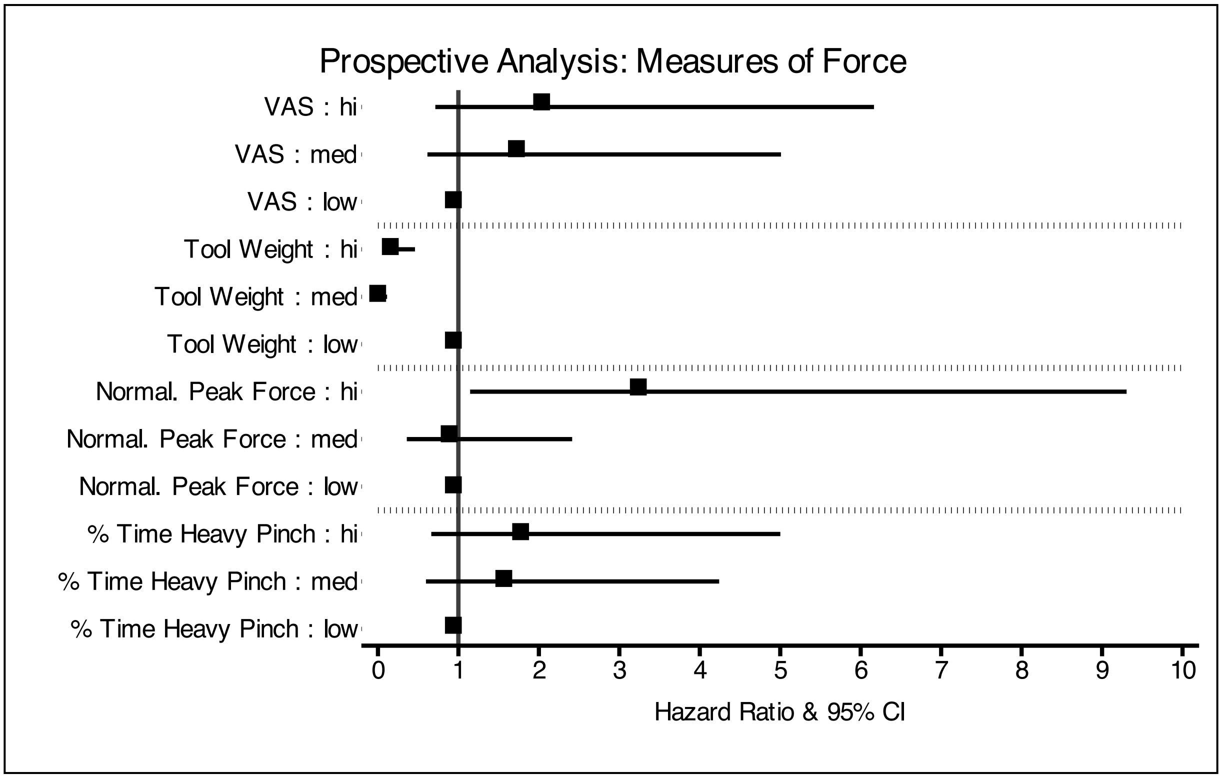


FIGURE 1b: Right Side: Hazard ratios for % time spent in various hand postures including: heavy pinch, heavy pinch or grip, any pinch or grip.

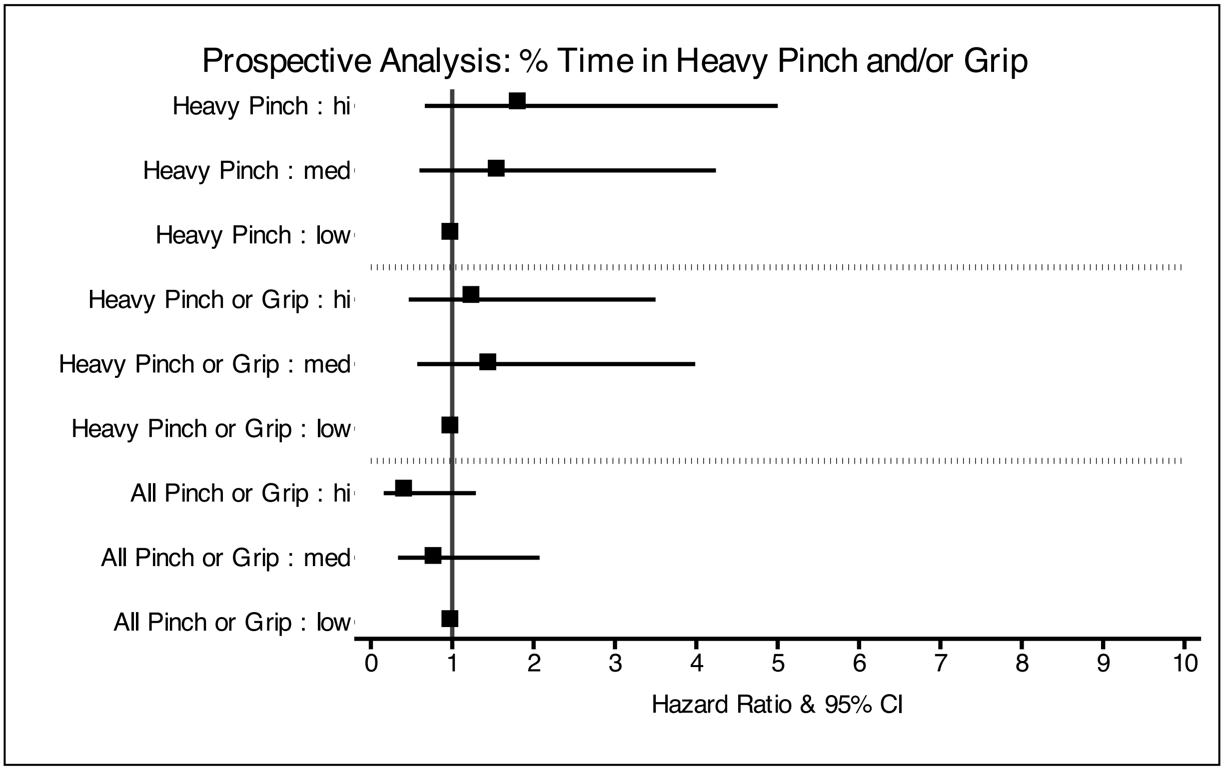


Figure 2a. Right Side: Hazard ratios for different measures of repetition including observer-rated HAL Scale and Speed of Work and video analysis of the repetition rate while any grip or pinch (total), and heavy grip or pinch.

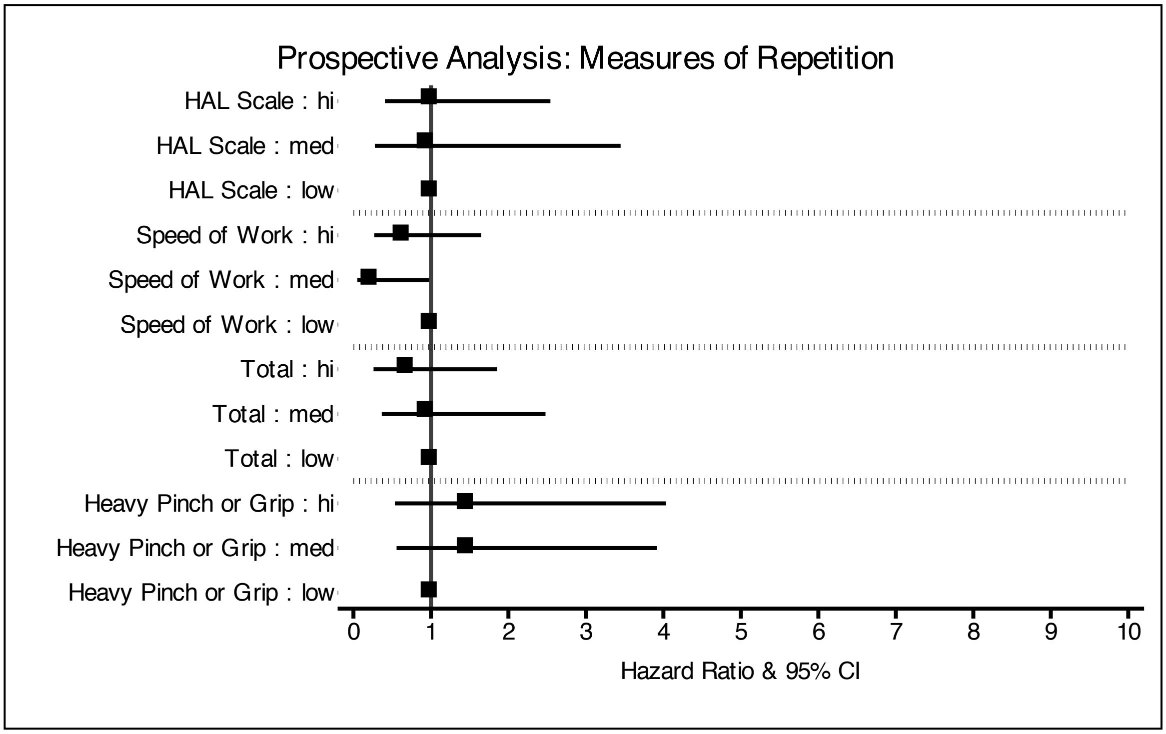


Figure 2b. Right Side: Hazard ratios for repetition rates while in heavy pinch, heavy grip, any pinch, and any power grip.

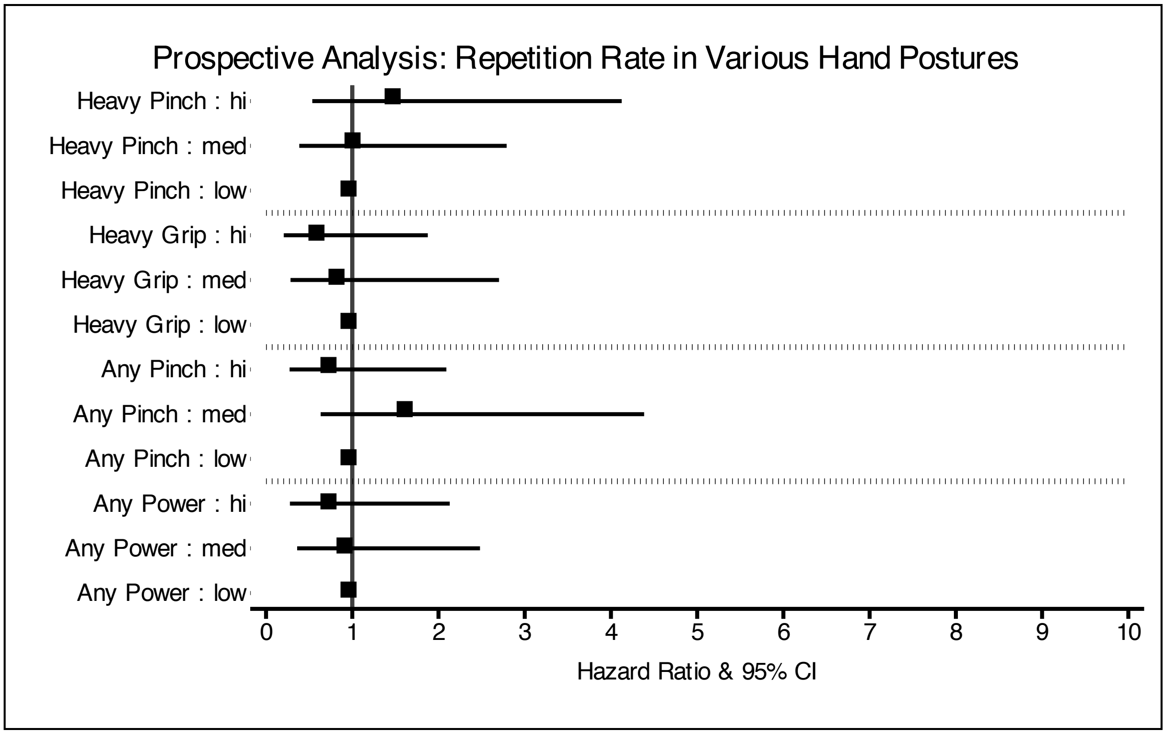


Figure 3a Right Side: Hazard ratios for % time spent heavy pinch adjusting for repetition as measured by: observer allocated HAL scale score; video analysis of total repetition rate; video analysis of heavy pinch or grip repetition rate (reps/min).

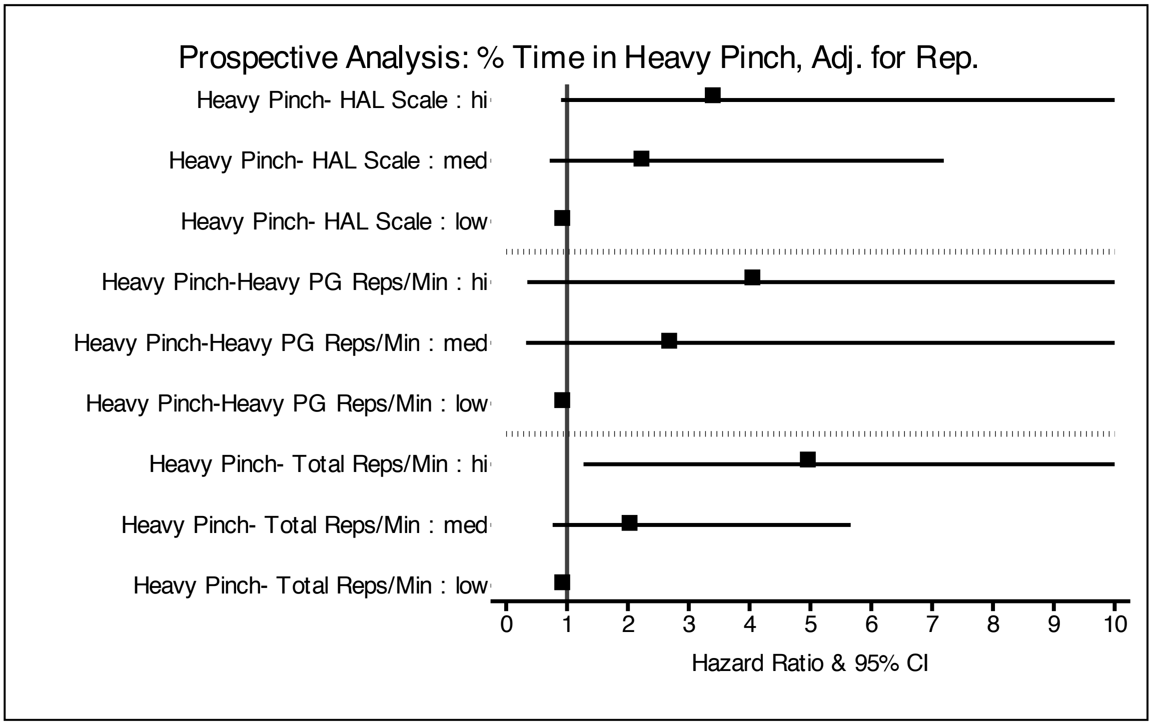


Figure 3b Right Side: Hazard ratios from exposure to repetition measured in 3 different ways: observer-rated HAL scale score; video analysis of total repetition rate; video analysis of heavy pinch or grip repetition rate (reps/min), controlling for % time in heavy pinch.

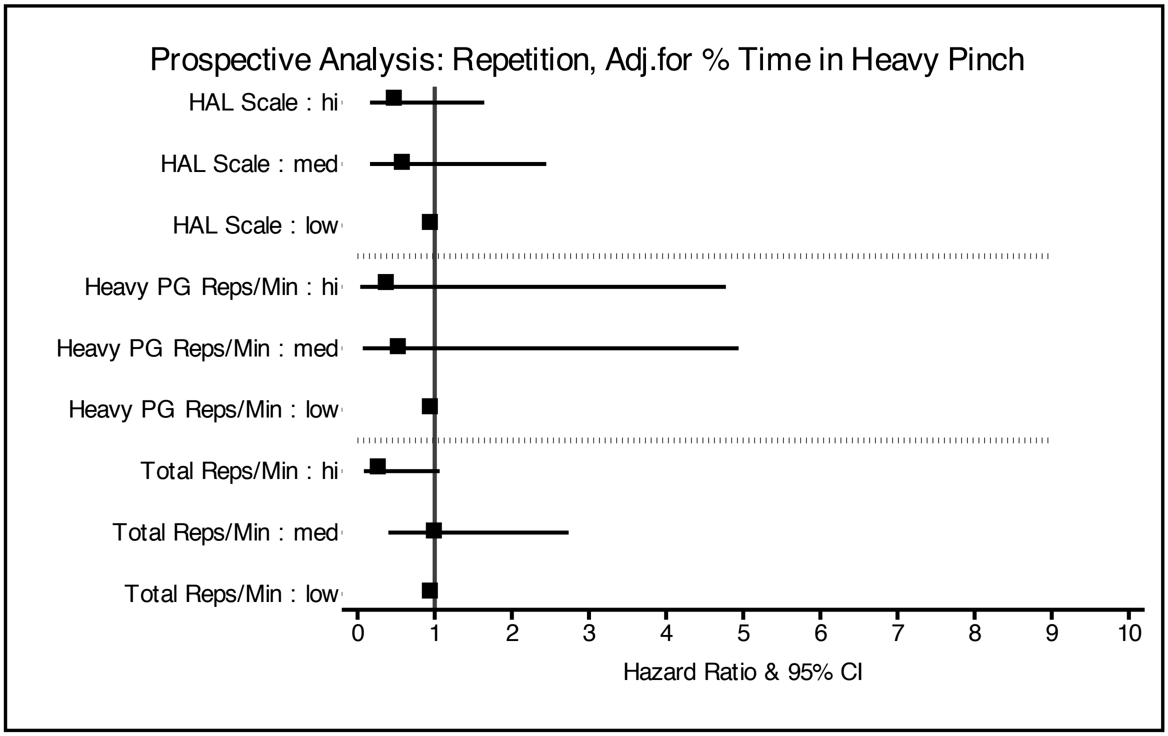
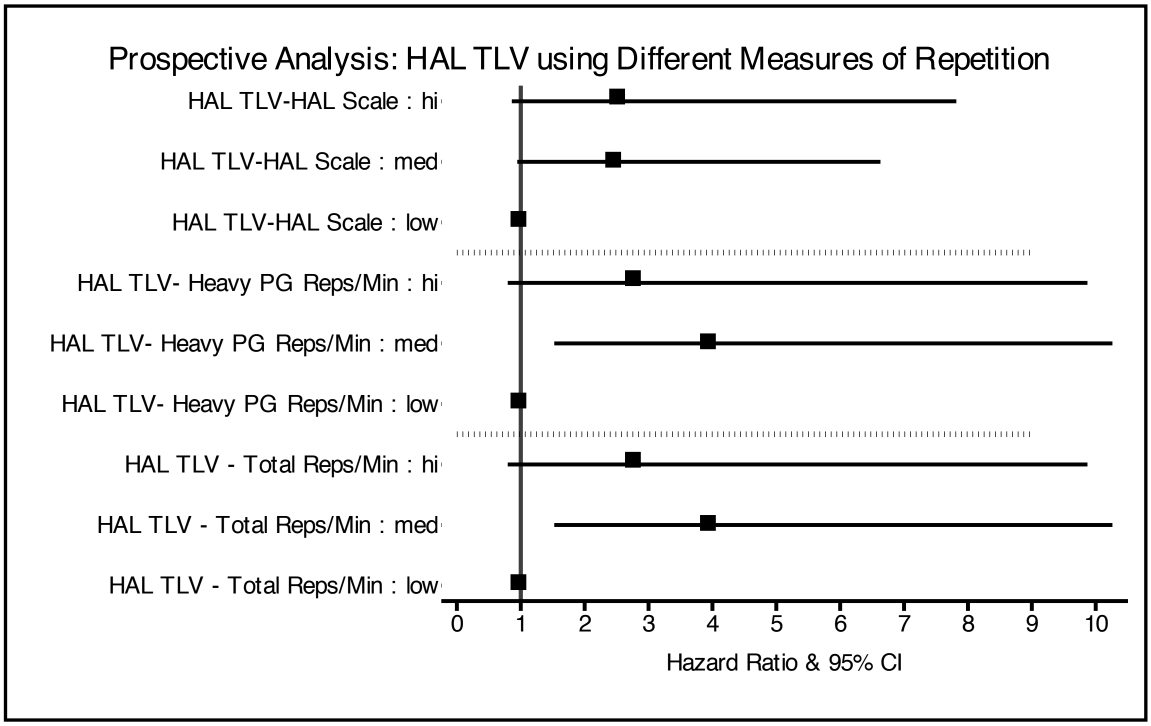


Figure 4 Right Side: HAL TLV hazard ratios using three different methods for Hand Activity Level scale: observer allocated; video analysis of total repetition rate; and video analysis of heavy pinch or grip repetition rate (reps/min).



Conclusions & Recommendations

Exposure Methods

Analyzing the correlation of various exposure measures was useful in identifying their levels of co-linearity and independence. Direct measurement methods such as tool weight, peak applied force, and matching grip or pinch forces had negative correlations with the percent time spent in no load and total repetition rate indicating that as grip force increased, the repetition rate decreased and, therefore, the time spent recovering increased.

Numerous methods for quantifying physical exposures in the workplace were utilized in this study. Of note, was a new method that quantified force based on video analysis that allocated each frame to one of five core hand postures including no load, light pinch(<=1kg), light grip(<=4kg), heavy pinch(>1kg) and heavy grip(>4kg). This method combined important characteristics of force including its duration, its magnitude, and the position of the hand while the force was being exerted. Based on the its low correlation with other direct measures such as tool weight, peak applied force and matching force measures, and its usefulness with predicting wrist tendinosis, it appears to be a more robust measurement method.

The strong correlation between the HAL Scale and the Speed of Work observer-rated scales suggests that differentiating between these two variables was difficult for the observer. The scales are intended to quantify the repetition rate in all hand postures. The scales' stronger correlation with the percent time spent in any grip versus any pinch could be based on the difficulty discerning distinct repetitions while in pinch. Given the higher repetition rate in heavy pinch, this could imply an underestimation of exposure for both scales. Additionally, the low correlation between the observer-rated efforts per minute and the total repetition rate in all five hand postures quantified via video analysis questions whether an observer can accurately quantify the repetition rate, particularly when the repetitions occur while in pinch. This is an important implication given the frequent use of these methods in the field and should be investigated further.

The within task analysis of the RPE and VAS scales was informative in discerning how different characteristics of the task affected the closeness of their ratings by workers. The strong overall correlation had enormous variability when assessed by task. The finding that the scales were rated within one point of one another when the task included a greater percentage of time in heavy pinch supports other emerging trends in the data that heavy pinch is an important component of worker fatigue and exertion. The comparison of this scale and other quantitative measures within tasks could be useful for understanding when more simple methods can be used in place of time intensive ones.

Exposures Associated with the Prevalence if Wrist Tendinosis

Although previous cross-sectional studies have looked at the associations between various risk factors, psychosocial factors and wrist tendinosis, doing so in the same cohort as the prospective analysis is important in differentiating factors that may be associated with the presence versus the incidence of wrist tendinosis. A better understanding of factors associated with the prevalence of wrist tendinosis may be important in secondary prevention efforts.

The majority of the thirty-seven prevalent cases at baseline were wrist extensor tendinoses with approximately half of all being tendinosis of the 1st Dorsal Compartment. The demographic factors that were associated with the prevalence of wrist tendinosis included being female, doing an hour or more of hand intensive activity per week, and having low job satisfaction. Both gender and job satisfaction has been shown to be associated with UEMSD's and could be important indicators of a worker in need of a more comprehensive approach to treatment to reduce the overall duration of injury. Further investigation of how these factors predict the duration of ones injury, their quality of life, and or their ability to do their normal job is needed.

In this analysis, all activity whether aerobic or hand intensive was treated equally, and in this case, was associated with increased incidence of wrist tendinosis. This was likely due to the large number of workers who reported house-cleaning activities. However, for some musculoskeletal disorders such as the low back, there is evidence that aerobic activities may actually be preventative. The association of hand intensive versus aerobic activities is worth more analysis in this cohort and in other studies.

The key finding in the cross-sectional analysis regarding force and wrist tendinosis was the association with the percent time in heavy pinch *and* grip, and how the association between the time spent in light pinch or grip reduced the risk of having wrist tendinosis. The protective factor of spending time in light pinch and grip was also seen for repetition indicating that it may be a combination of force and repetition that is responsible for its protective association. Also of interest, is that repetition in heavy pinch and grip was associated with the prevalence of wrist tendinosis, particularly in the medium exposure group. It was interesting that the high exposure group had a lower risk of having wrist tendinosis than the medium group. The same pattern was seen when quantifying repetition using the HAL scale, or basing repetition rate on heavy pinch postures alone. This indicates that workers in jobs that have high exposure may self select out of those jobs due to their discomfort or injury, and those who are moderately exposed may be able to manage the discomfort while doing their job. More analysis of factors that are associated with work disability may be helpful in understanding this important finding.

Exposures Associated with the Incidence of Wrist Tendinosis

The time spent in heavy pinch was the most significant predictor of wrist tendinosis, and the relationship followed a dose response pattern. The medium exposure group spent between 10% and 30% of their time in pinch activities requiring greater than 1kg of force, and the high exposure group spent over 30% of their time engaging in tasks requiring over 1kg of pinch force.

The risk of developing wrist tendinosis decreased as more time was spent in power grip even if the grip was forceful. Workers who spent up to 50% of their time in light pinch (<=1kg) did not have the same risk of injury, and workers spending up to 20% of their time in light or heavy grip were protected from injury.

When adjusting time in heavy pinch with different measures of repetition, the hazard ratio increased nearly two fold for both the medium and high groups indicating that high pinch force alone is an important predictor of right wrist tendinosis. This appears a robust relationship given that the pattern is preserved after adjusting for different measures of repetition.

The strong relationship between wrist tendinosis and the percent time in heavy pinch may be associated with the higher incidence of tendinosis of the abductor pollicis longus (deQuervains tenosynovitis), a tendon that is very active during pinch.

Identifying the percent time in heavy pinch as a strong predictor of right wrist tendinosis was very important to understanding it as a causal factor, and identifying a threshold that can be recommended in the workplace to reduce the incidence of wrist tendinosis. However, there are challenges for ergonomists, clinicians, and safety personnel applying the video analysis method in the field, primarily due to the time consuming aspect of the analysis of the video. Interestingly, the high exposure quantified by normalized peak force (NPF) was also predictive of right wrist tendinosis. Despite the NPF being based on force matching values, it was more predictive than force matching alone. The advantage to using the normalized peak force method to identify workers at risk of wrist tendinosis is that it is simple and efficient to implement in the field without the need for any laboratory analysis.

Challenges & Limitations

Some of the exposure variables have little data making it challenging to include in the univariate and multivariate analysis. The large variation of time that individuals contributed to the study was not ideal, nor was the reliance on workers self-report of weekly task duration used for time-weighted averages. The small sample size suggested the use of exposure cutoff points to be made based on having an equal number of cases in each group. This makes direct comparisons between exposure groups in different hand postures challenging. For example, the high exposure group for heavy grip spent three percent of their time or more in grip versus the heavy pinch high exposure group which had to be exposed for a longer duration (30%). The lack of association between the percent time in heavy grip and wrist tendinosis in this cohort could be due to the relatively little time they spent in heavy grip. This limitation would not affect the findings regarding the percent time spent in heavy pinch.

Recommendations

To conclude, in this 28-month prospective study on blue collar workers, the percent time in heavy pinch was the measure most predictive of right wrist tendinosis, particularly when adjusted for repetition. The ACGIH-TLV for Hand Activity level and the strain index were two composite measures that were also effective predictors of right wrist tendinosis. The percent time spent in power grip was not a significant workplace predictor, nor were any of the measures of repetition. Individual factors including job satisfaction, general health, and BMI were not significant predictors, but gender was. The most predictive measure of force was the video based data quantifying the percent time spent in high force and there was no difference evident between the three methods for quantifying repetition. A dose response relationship appeared evident in the percent time spent in high force pinch and indicates that spending less than 10% of ones time in tasks requiring pinch forces greater than 1kg of force is important in reducing their risk for developing wrist tendinosis. Interventions designed to reduce the magnitude of pinch below 1kg could substantially increase (48%) the amount of time that workers could engage in tasks requiring pinch, without increasing their risk of wrist tendinosis. This study is an important contribution to our understanding of causal factors for wrist tendinosis since it is the only known prospective study looking dose response relationships between physical risk factors and wrist tendinosis in the work place.

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