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Association between wrist angle and carpal tunnel syndrome among workers

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By

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Abstract

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Introduction

Carpal Tunnel Syndrome (CTS) is the most common work-related peripheral neuropathy among workers who perform hand-intensive tasks. It has a greater impact on time away from work and disability than almost all other workplace injuries. For prevention, the National Institute of Occupational Safety and Health recommends reducing four primary biomechanical risk factors: hand tool vibration, grip and pinch force, repetitive hand exertions, and awkward wrist posture. However, the findings from studies evaluating the relationship between wrist posture and CTS are inconsistent. Few studies have measured wrist postures of workers and very few studies have been prospective in design. This dissertation presents a meta-analysis evaluating the effects of wrist posture on CTS among workers followed by an analysis of wrist posture risk from a large prospective study of blue-collar workers.

Method

A meta-analysis reviewed the findings from prior studies that investigated the association between wrist posture and CTS and calculated a pooled relative risk.

In addition, data was collected from a 28-month prospective study of 447 blue-collar workers at four industrial sites in the U.S. These workers were followed with symptom surveys and nerve conduction studies at the wrist to identify incident cases of CTS. Video recordings of the workers performing their usual tasks were analyzed for grip type and wrist posture. Inter-observer reliability of wrist posture measurement was examined

using Interclass Correlation Coefficients (ICC) and Kappa coefficient. Using each worker's task exposure and estimated time on task, a time weighted average exposure metric was calculated for several measures of wrist posture. A survival analysis assessed the relationship between wrist postural risk factors and incident cases of CTS. The final multivariable models were adjusted for confounding.

Result

Nine epidemiologic studies met the inclusion criteria for the meta-analysis. The pooled relative risk of work-related CTS increased with increasing hours of exposure to wrist deviation, or extension/flexion [RR = 2.01; 95% CI: 1.646-2.43; $p < 0.01$; Shore adjusted 95% CI 1.32 to 2.97]. The inter-rater reliability for wrist posture measures from video found moderate (Kappa = 0.48) to substantial (Kappa = 0.64) agreement between observers across the five different types of grip. The ICC ranged from 0.57 and 0.67 with the highest correlation for high-force power grip.

Job level measures of wrist posture were merged with other data from the prospective study. During the 28 months of follow-up there were 29 incident cases of dominant hand CTS. Multivariable analysis indicated that the hazard ratio for CTS more than doubled with the combined exposures to wrist extension and forceful (> 10 N) pinch. The HR, after adjusting for age, gender, BMI, and medical history, was 2.83 (95% CI 0.91-8.76; p-value <0.2), where the cutoff between low and high exposure was 6.07 degree mean wrist extension.

Discussion and conclusion

We found that exposure to wrist extension, especially during the application of forceful pinch grip increased the risk of CTS. A new method for estimating posture from videos was developed and found to have good inter-rater reliability; levels of reliability that are higher than prior studies. Recommendations are made for video analysis methods for estimating wrist posture. The analysis of the prospective data suggests that reducing mean wrist extension, if above 6 degrees, or reducing the combination of wrist extension and high-force pinching will reduce CTS risk among blue-collar workers in hand intensive jobs. Workplace interventions should incorporate training and engineering interventions to reduce sustained exposure to these factors. These findings may be useful in the design of workplace safety programs to prevent CTS in order to keep our workers healthy and productive.

Dit proefschrift is
gewijd aan
mijn oranje ridder.

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Chapter 1

1. Introduction

1.1. Motivation

Carpal Tunnel Syndrome (CTS) is the most prevalent work-related peripheral neuropathy among workers who perform hand-intensive tasks. According to the Bureau of Labor Statistics (BLS), 10,300 incidents of CTS were reported in the U.S. during 2011 (BLS, 2012). In the US, 450,000 workers required surgical treatment with an annual estimated cost of $2 billion dollars (Dale et al., 2013; Luckhaupt et al., 2013). These disorders impact the quality of the workers' lives and may eventually lead to a job change (Turner et al., 2004).

The four primary biomechanical risk factors of CTS include vibrating hand tools, grip and pinch force, repetitive hand exertions, and awkward wrist posture (NIOSH, 1997). Previous CTS studies focused primarily on the risk factors of hand force and repetition rate due to the difficulty of specific exposure assessment. The few studies which examined exposure to awkward wrist posture were conducted in cross-sectional studies with limited quality of posture exposure assessment.

This dissertation will examine the effect of wrist posture on CTS development among blue-collar workers. The ultimate goal of this line of study is to provide practical information for health and safety programs to reduce the risk for CTS among workers who perform hand-intensive work. This information should be useful to employers, employees, industrial engineers and health and safety specialists.

1.2. Prevalence and incidence of CTS

The prevalence and incidence of CTS varies by population and case definition. In the general population in Sweden the prevalence of CTS based on the case definition of paresthesias in the median nerve distribution of the hand (no nerve conduction study) is 14.4%, while if the definition includes the requirement of abnormal nerve conduction, the prevalence drops to 4.9%. (Atroshi, Gummesson, Johnsson, Ranstam, & Rose, 2012). A similar prevalence rate for symptom based CTS (16.3%) has been reported in the US population (Papanicolaou, McCabe, and Firrell 2001). The incidence rate of CTS in the general population ranges from 1.7 to 3.46 per 1000 person-years using population-based estimation (Dieleman, Kerklaan, Huygen, Bouma, & Sturkenboom, 2008)(Nordstrom, DeStefano, Vierkant, & Layde, 1998)(Mondelli, Giannini, & Giacchi, 2002).

CTS prevalence and incidence rates in working populations are higher than the general population and vary by job type (Johansson, 1994). Overall prevalence among US workers, based on the 2010 National Health Interview Survey, was 6.7% among current/recent workers (Luckhaupt et al 2012). Dale et al reported a prevalence of 7.8%

among approximately 4500 US workers who perform hand intensive work based on abnormal symptoms and nerve conduction (Dale et al 2013). In France, general worker population surveys report a prevalence of 2.3% (1.5–3.0) (Roquelaure et al., 2006). In a Washington State population study of manufacturing workers, the CTS prevalence was 10.8% (95% CI 7.8-13.7%) (B. A. Silverstein et al., 2010). In a study of young construction workers in Missouri the prevalence was 3.0% (T. Armstrong, Dale, Franzblau, & Evanoff, 2008) while among workers in the meat packing industry the prevalence is as high as 21% (Gorsche et al., 1999). Difference in prevalence is likely to be due to differences in work schedule, break patterns and hand loads. Silverstein et al. studied 652 workers and observed a prevalence of 0.6% among workers in low force and low repetitive jobs and 5.6% among workers in high force and highly repetitive jobs (B. Silverstein, Fine, & Armstrong, 1987).

The incidence of CTS in the working population has recently been evaluated in prospective studies and is higher than in the general population. A 2-year prospective study of health care and service workers reported an incidence of 5.11 per 100 person-years.(Burt et al., 2012) Dale et al. reported an overall incidence rate of 2.3 CTS cases per 100 person-years in a pooled study of workers across the U.S.(Dale et al., 2013) A number of studies indicated significant risk for CTS incidence as workplace and individual factors, such as prolonged forceful exertion, ACGIH TLV, female gender, aging, and high BMI. (Bonfiglioli et al., 2012; Garg et al., 2012; Burt et al., 2013, Dale et al., 2013; Harris-Adamson et al.,2013)

1.3. Impact of CTS on workers and employers: disability and cost

CTS has a greater impact on time away from work and disability than almost all other workplace injuries. CTS leads to productivity loss before, during, and after treatment of CTS with an average loss of 28 days per year per worker (Fagarasanu & Kumar, 2003) (BLS, 2012; Foley, 2007). Furthermore, 18% of workers leave their jobs within 18 months after developing CTS. (Faucett, Blanc, & Yelin, 2000). The economic burden of CTS to workers and society is large. In 2006, approximately $2 billion was spent on carpal tunnel release operations for workers (Stapleton, 2006). In addition, the average income loss per CTS claimant is $45,000 to 89,000. (Foyer, Silverstein, and Polissar 2007)

1.4. Definition of CTS

CTS is an entrapment of the median nerve in the wrist which causes a localized peripheral neuropathy affecting sensation of the fingers (thumb, index finger, middle finger, and half of ring finger) and strength of the thumb APB muscle (Barcenilla, March, Chen, & Sambrook, 2012a; B. Silverstein et al., 1987; R. Werner, Armstrong, Bir, & Aylard, 1997). The conventional diagnostic criteria for CTS include both (i) the presence of paresthesia (numbness, tingling, burning, or pain) in fingers of hand median nerve distribution and (ii) abnormal median nerve conduction across the wrist (Harris-Adamson et al., 2013; Rempel et al., 1998). It should be recognized that abnormal nerve conduction study criteria may vary between neurologists and other clinicians and conduction latencies and are influenced by temperature and methodology.

1.5. Non-work related risk factors of CTS

Non-occupational demographic factors contribute to the development of CTS. Several epidemiology studies have found significant association between age (>40), female gender, obesity (BMI>30), and pregnancy (Atroshi, 1999; Boz, Ozmenoglu, Altunayoglu, Velioglu, & Alioglu, 2004; Solomon, Katz, Bohn, Mogun, & Avorn, 1999; Stevens, Beard, Ofallon, & Kurtland, 1992; Tanaka et al., 1995). For example, female workers are at elevated risk for CTS (HR=1.30) and the risk increases linearly with both age and BMI (Harris-Adamson et al., 2013).

Besides the demographic risk factors, systemic conditions (e.g., rheumatoid arthritis, diabetes, and thyroid disease), and other distal upper extremity disorders may also by predictors for CTS.(Stevens et al., 1992; Chammas et al., 1995; Solomon et al., 1999; Geoghegan et al., 2004; Bonfiglioli et al., 2012; Garg et al., 2012; Burt et al., 2013, Dale et al., 2013; Harris-Adamson 2013). There is limited evidence of association with smoking (Geoghegan et al., 2004).

1.6. Work related risk factors for CTS

Both workplace psychosocial and biomechanical factors have been associated with CTS (see Table 1). The biomechanical factors include hand force, wrist repetition rate, awkward posture, contact pressure, vibration due to tool use and combined indexes such as HAL TLV[1] or strain index (SI) (Armstrong & Chaffin, 1979; Moore & Garg 1995; Fagarasanu & Kumar, 2003).

Forceful hand exertions during repetitive tasks have been linked to CTS (Roquelaure et al., 1997, 2008; Viikari-Juntura & Silverstein, 1999; Violante et al., 2007). Roquelaure observed that a forceful task requiring more than 1 kg of force, is strongly associated with CTS (case-control study OR: 9.0)(Roquelaure et al., 1997). Recently, a cross-sectional study of health care and manufacturing workers showed that workers who perform high force gripping (task that requires > 70% MVC versus <20% MVC) are at increased risk for CTS [OR of 2.74; 95% CI 1.32-5.68) (Burt et al., 2011). In the prospective study of the same population the authors reported a strong relationship with the percent time performing a high force grip and the development of CTS (Burt et al., 2013). Barcenilla

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[1] Hand Activity Level Threshold Limit Value

reported a significant association between force and CTS risk (OR 4.23 (95%CI 1.53-11.68) p-value <0.05) in their meta-analysis study (Barcenilla, March, Chen, & Sambrook, 2012b).

Repetitive hand activity may be an independent risk factor for CTS. Tasks involving rapidly repeating the same hand motions (less than 10 sec/task) are associated with increased CTS risk (OR: 8.8) (Roquelaure et al., 1997). Other studies have reported a similar risk (Tanaka et al., 1997; Robert a Werner, 2006; Wieslander, Norbäck, Göthe, & Juhlin, 1989). The pooled OR from a meta-analysis of 11 studies reported a for risk of repetition of 2.26 (95%CI 1.73-2.94) (Barcenilla et al., 2012b). A recent cross-sectional study with 1108 workers reported increased OR compared to the reference group (OR 2.37 (95% CI 0.67-8.35) (Armstrong et al., 2008).

Combining biomechanical risk factors into an index has also been used to assess risk. Combined indexes may be preferred due to logistic convenience and comprehensiveness. An example is the American Conference of Governmental Industrial Hygienists threshold limit values for hand activity level (ACGIH[2] TLV for HAL). A task that with exposure above the TLV leads is associated with a three-fold increased risk (IRR: 3.32 95% CI 2.34-4.72) for CTS (Bonfiglioli et al., 2013). Another combined index is the Strain Index (SI). SI is a semi-quantitative work related risk factor evaluating index that includes intensity of exertion, duration of exertion per cycle, efforts per minute, wrist posture, speed of exertion, and duration of task per day. Similar to the TLV, an increase of one SI unit increases risk of CTS incidence by five-fold higher ($p<0.05$)(Garg et al., 2012).

Contact stress is a load applied over the carpal tunnel that can increase pressure on the tendons and nerve that passes through the carpal tunnel (R Werner, Franzblau, Albers, & Armstrong, 1997). A number of studies report increase of carpal tunnel pressure with to contact stress (Szabo & Chidgey, 1989) (Armstrong, Castelli, Evans, & Diaz-Perez, 1984; Keir, Bach, & Rempel, 1998).

Workplace psychosocial factors may also increase the risk of CTS (Bongers, de Winter, Kompier, & Hildebrandt, 1993; Lundberg, 2002). A recent large prospective study reported that psychosocial factors such as high job strain can double the risk of CTS (HR=1.86; 95% CI 1.11 to 3.14) (Harris-Adamson et al., 2013).

1.7. Wrist posture and CTS

Awkward wrist posture may play a role as a risk factor for CTS among workers performing hand-intensive work. According to a review by the National Institute of

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[2] Governmental Industrial Hygienists (ACGIH)

Occupational Safety and Health (NIOSH), a neutral wrist posture is recommended for work to avoid increased risk of CTS (NIOSH 1997). De Krom reported that frequent wrist flexion and extension, and bending or twisting of the hands over 31˚, are risk factors for CTS. However, the role of wrist posture has not been well studies and the findings of prior studies are inconsistent. In 1987, Silverstein et al. reported that working with an awkward wrist posture was not a significant predictor of CTS (B. Silverstein et al., 1987). However, in a review 10 years later, Viika-Juntra and Silverstein concluded that non-neutral wrist posture was a risk factor for CTS (Viikari-Juntura & Silverstein, 1999). The studies that evaluate wrist posture are cross-sectional and not prospective and have limitations of small sample size and little job variety.

CTS occurs where the median nerve passes through a tight space formed by inelastic tissue boundaries of the carpal tunnel at the wrist (Holmes, Howarth, Callaghan, & Keir, 2011). The median nerve traverses the carpal tunnel, bounded by the carpal bones and flexor retinaculum, and is surrounded by nine finger flexor tendons that pass through the carpal tunnel (Konz & Mital, 1990; Phalen, 1966). Carpal tunnel pressure increases during wrist extension or flexion and this compresses the nerve and synovium causing tissue deformation and ischemia (Rempel, Dahlin, & Weden, 1999)(D. Noah, Leonard, Todd, Yuen, & David, 1995; Holmes et al., 2011; P J Keir et al., 1998; Peter J. Keir, Bach, Hudes, & Rempel, 2007) (Phalen, 1966)(Figure 1.1). Keir reported that 33˚ of wrist extension and 49˚ of wrist flexion are postures associated with physiologic levels of tissue pressure elevation for 25% of the general population (Keir et al., 2007).

Wrist posture assessment on jobs may be an important factor in injury prevention. Addressing non-neutral wrist postures through tool and workstation design may be an effective preventative intervention that does not sacrifice productivity. In addition, changed to tools and tasks that improve posture may reduce fatigue and improve productivity. A number of studies have demonstrated decreased injury risk with changes in tool or workstation design. An ergonomic intervention study among engineers found that using an alternative mouse had a protective effect on incident cases of right upper extremity musculoskeletal disorders (HR 0.57, 95% CI 0.24 to 1.34) (Conlon, Krause, & Rempel, 2008). Use of a split keyboard, that reduces non-neutral wrist posture can reduce wrist and forearm pain (Tittiranonda, Rempel, Armstrong, & Burastero, 2000).

It is, however, difficult to conduct workplace studies of wrist posture. Accurate measurement of wrist posture in the field without interfering with work is challenging. Previous workplace wrist angle assessments have included workers' self-reports, real-time observation by ergonomists, electro-goniometers, motion capture systems, and use of inclinometers (Burdorf, Derksen, Naaktgeboren, & Riel, 1992; Kilbom, 1994). Some of these methods may lead to exposure misclassification due to reporting bias or poor precision (workers' self-report and real-time observation); the instruments may alter task performance (electro-goniometers and motion capture systems), and spurious values may be due to dynamic effects (inclinometers). All of these concerns relate to the reliability of the estimated wrist posture. An alternative assessment method—observational posture analysis by video recording (Fransson-hall, Gloria, Kilbom, Karlqvist, & Wiktorin, 1995)—was implemented in this study to reduce the bias, imprecision, and other limitations.

1.8. Dissertation overview and objectives

The overall purpose of this research is to evaluate the relative importance of wrist posture as a risk factor for CTS using data collected in a prospective study of blue-collar workers.

Chapter 2 is a review of the literature and meta-analysis that examines the evidence of relationship between wrist posture and risk of work-related CTS. The review uses keywords: work-related, carpal tunnel syndrome, wrist posture, and epidemiology. The findings from identified studies were pooled to estimate an overall effect size and relative risk. The heterogeneity of studies was investigated by using a fixed-effect model and a funnel graph. Publication bias was evaluated by conducting Egger's test. The main contribution of this chapter is the conclusion that the risk of CTS is increased with exposure to prolonged non-neutral wrist postures among industrial and service workers. The chapter is in review at the journal Safety and Health at Work.

Chapter 3 assesses the reliability of using video analysis of workers performing their usual tasks to estimate wrist extension and flexion. Lack of exposure measures for wrist posture is an obstacle to establishing a quantitative exposure–response model. Lack of exposure response data has limited design of prevention programs for CTS. In Chapter 3, we estimated wrist posture of workers using a novel method that improved the precision of measurement compared to prior video analysis methods. From 333, 15-minute video clips of different subjects and tasks we randomly selected 65 task videos. Three trained observers estimated wrist angle from 45 randomly selected frames from each video. Inter-rater reliability was examined by calculating the Kappa statistic and interclass correlation coefficient. The study found that the new methods increased the reliability of posture measurement (0.64 Kappa coefficient and 0.67 ICC) compared to prior studies. A manuscript based on these findings is in review at the journal Applied Ergonomics.

Chapter 4 used data from a prospective study of 450 blue-collar workers to estimate the contribution of wrist posture to the incidence of CTS after adjustment of confounding factors. The conceptual hypothesis of this study was that subjects who are exposed to tasks that require increased extension or flexion for a prolonged time are at increased risk for developing CTS. The chapter begins with a description of wrist angles and hand grip types in the study population. Univariate and multivariable analysis were conducted to estimate the association between the wrist angle and CTS by using regression statistics for cross-sectional and prospective analysis. An exposure–response model is presented at the conclusion. The findings indicate that the combination of wrist extension with high force pinch poses an increased risk for CTS.

Chapter 5 summarizes the main findings of the thesis and makes recommendations for future research.

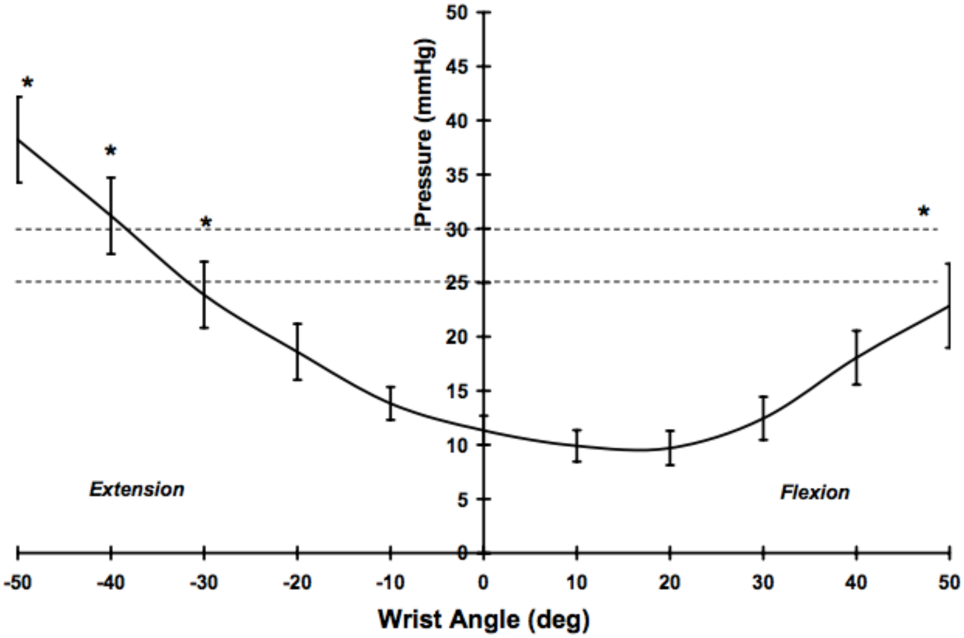

Figure 1 Carpal tunnel pressure change due to wrist extension-flexion angle (Unit in degree). Adapted from Keir 2007 Figure1.

Table 1 Carpal tunnel syndrome risk factors established from NIOSH report (NIOSH 1997)

Occupational risk factors	Demographic risk factors
Applied force on hand	Age (>40yrs old)
Repetition rate of wrist movement	Gender (Female)
Awkward wrist posture	Obesity
Contact pressure	Diabetes
Temperature	Pregnancy
Hand vibration	Hand preference
	Previous musculoskeletal disorder history

Chapter 2

2. Meta-analysis: association between wrist posture and carpal tunnel syndrome among workers

2.1. Abstract

Objectives: Carpal Tunnel Syndrome (CTS) is a common work-related peripheral neuropathy. In addition to grip force and repetitive hand exertions, wrist posture (hyperextension and hyperflexion) may be a risk factor for CTS among workers. However, findings of studies evaluating the relationship between wrist posture and CTS are inconsistent. The purpose of this paper was to conduct a meta-analysis of existing studies to evaluate the evidence of the relationship between wrist posture at work and risk of CTS.

Methods: PubMed and Google Scholar were searched to identify relevant studies published between 1980 to 2012. The following search terms were used: work-related, carpal tunnel syndrome, wrist posture, and epidemiology. The studies defined wrist posture as the deviation of the wrist in extension or flexion from a neutral wrist posture. Relative risks (RRs) from individual studies were pooled to evaluate overall risk of non-neutral wrist posture on CTS.

Results: Nine studies met the inclusion criteria. All were cross-sectional or case-control designs and relied on self-report or observer estimates for wrist posture assessment. The pooled RR of work-related CTS increased with increasing hours of exposure to wrist deviation, or extension/flexion [RR = 2.01; 95% CI: 1.646-2.43; $p < 0.01$: Shore adjusted 95% CI 1.32 to 2.97].

Conclusions: We found evidence that prolonged exposure to non-neutral wrist postures is associated with a two-fold increased risk for CTS compared to low hours of exposure to non-neutral wrist postures. Workplace interventions to prevent CTS should incorporate training and engineering interventions that reduce sustained non-neutral wrist postures.

Keywords: systematic review, Carpal Tunnel Syndrome (CTS), meta-analysis

2.2. Introduction

Carpal Tunnel Syndrome (CTS) is the most common form of work-related peripheral neuropathy among blue-collar workers who perform hand-intensive tasks. (Stapleton2006) In addition to grip force and hand repetition, wrist posture (sustained or repeated extension or flexion) may lead to an increased risk of CTS among workers. However, the findings of prior studies evaluating the relationship between wrist posture and CTS are inconsistent. Silverstein et al. (1987) found that working with an awkward wrist posture is not a significant predictor of CTS, while Viika-Juntra et al. (1999a) reported a significant association between risk of CTS and awkward wrist posture.

Distal upper-extremity musculoskeletal injuries among workers are an important cause of work-related disability, cost and reduced productivity. Common distal upper extremity injuries include medial/lateral epicondylitis (elbow), wrist tendonitis, and carpal tunnel syndrome. CTS affects five million workers in the U.S. (Luckhaupt 2010) and the cost of medical care has been estimated to be over $2 billion annually. (Dale 2013) In addition, these disorders impact the quality of workers' lives and may lead to job change. (Turner 2004)

CTS occurs when the median nerve is compressed within the tight space of the carpal tunnel. Forceful hand intensive work can lead to elevated pressures within the carpal tunnel and persistent tissue edema and nerve compression. (Rempel1999) Keir et al. reported that the median nerve can be damaged due to high pressure on the carpal tunnel from extreme wrist extension or flexion. (Keir1997; Keir1998) This physiological evidence supports a hypothesis that sustained awkward wrist postures may lead to CTS among workers. However, according to a 1997 National Institute of Occupational Science and Health (NIOSH) review, there was insufficient evidence to link sustained wrist deviation to CTS incidence. (NIOSH 1997)

The present meta-analysis reviews evidence of an association between CTS and wrist posture in epidemiologic studies. The main question addressed was whether or not there are consistent associations between CTS incidence and prolonged exposure to non-neutral wrist extension or flexion among workers.

2.3. Materials and methods

2.3.1. Search

For this meta-analysis, a systematic search was conducted using PubMed and Google Scholar for studies published from 1980 to 2011. The keywords of the search included *work-related*, *carpal tunnel syndrome, wrist posture*, and *epidemiology*.

2.3.2. Inclusion and Exclusion Criteria

The following inclusion and exclusion criteria were used. Papers had to be published in the English language. Only epidemiological studies that used case-control, cohort, and cross-sectional designs were included; anecdotes or case series were excluded. Studies of office workers were excluded because their risks factors, sustained awkward postures and contact stress, are substantially different from industrial work. Studies were excluded if they did not report the size of difference between groups (effect size) with the 95% Confidence Interval (CI) in the form of an odds ratio (OR) or relative risk (RR) adjusted to age and gender. Studies were excluded if they did not report a quantitative or semi-quantitative measure of exposure of wrist angle. A summary of inclusion and exclusion criteria is provided in Table 1. Nine studies met the inclusion criteria based on study design and exposure measurement methods.

2.3.3. Definition of outcome and exposure

A typical CTS case definition included (i) the presence of paresthesia (numbness, tingling, burning, or pain) in the fingers of the median nerve distribution in the hand (one or more of the thumb, index or middle finger) and (ii) abnormal median nerve conduction test result consistent with CTS. (Rempel, 1998) Some studies used both symptoms and abnormal nerve conduction tests to diagnose CTS, but two studies used just symptoms consistent with CTS.

The exposure variable of the reviewed studies was wrist deviation in extension or flexion from a neutral wrist posture or duration of time at work with the wrist in a non-neutral posture. Wrist posture was estimated by (1) direct observation of workers performing their usual work, (2) direct measurement from videos of the workers performing their usual work, (3) worker self-report of wrist angle and time or frequency in non-neutral wrist postures, or (4) use of job title surrogate to infer the wrist posture.

2.3.4. Statistical Analysis: This study pooled RR values between reference groups and the highest exposure group of each study. Measures of effect (OR, RR), the 95%CI values and sample size were summarized in tables. The summary effects of specific exposure risks were calculated using STATA, version 12 (StataCorp, College Station, TX, U.S.A). A fixed-effects model was applied after a test for heterogeneity quantified by the chi square value and degrees of freedom. Publication bias analysis was conducted using funnel plot and Egger's test.

2.4. Results

The nine studies that met the inclusion criteria are summarized in Table 3. Six were cross-sectional and three were case-control study designs. The exposure assessment methods of wrist posture included direct observation, measurement from video of the job, job title surrogate, and self-reported (Table 2). The definition of the exposure groups varied between studies. Five studies defined exposure groups based on estimated specific wrist extension or flexion angles. (Feldman 1987; de Krome 1990; Barnhart 1991; Marras 1993; Osorio 1994) Two studies also defined the exposure groups based on working for a prolonged time period with non-neutral posture. (de Krome 1990; Tanaka1995) The pooled RR from nine studies demonstrated positive associations of increased relative risk of CTS with increased exposure to wrist extension/flexion (Figure 1; RR = 2.01 [1.66-2.43]). One study (Marras 1993) contributed 49% of the weight to the pooled RR.

2.4.1. Selection bias

There were twice as many cross-sectional studies as case-control studies and no cohort studies were identified. For the six cross-sectional studies, the pooled RR was 1.87 [1.50-2.32] (Table 4). For the three case-control studies, the pooled RR was 2.38 [1.63-3.48] (Table 4).

2.4.2. Information bias

Information bias may be influenced by exposure assessment methods and was evaluated by sensitivity analysis. The pooled RR for studies with common exposure assessment methods were: (1) self-report exposure studies (RR=2.95 [2.24-3.89] p-value<0.005), (2) surrogate exposure studies (RR= 4.63 [1.46-14.67] p-value<0.01), and (3) observational exposure studies (RR=1.44 [1.13-1.83] p-value <0.005).

2.4.3. Confounding bias

None of the studies evaluated separately the relationships between exposure to wrist posture and exposures to other biomechanical factors such as applied hand force or repetition rate. Therefore, confounding may exist. That is, RR will be increased if expose to non-neutral wrist postures occurred with forceful or highly repetitive work or RR may decrease in the opposite situation. There was no way to estimate whether important confounding was present or not.

2.4.4. Consistency of findings

The heterogeneity test result of 9 studies showed X^2 =37.06 (p-value <0.01). However, all studies demonstrated a positive association between CTS and increased exposure to non-neutral wrist posture. The pooled RR of the random effects model is 3.13 (95%CI 1.84 to 5.33; Shore adjusted 95% CI 1.32 to 2.97.)

2.4.5. Publication bias

Seven studies are located on the right side of funnel graph and their risk estimates are clustered near the pooled RR. However, only two studies are on the left top side of the funnel plot and smaller size studies with increased risks or reduced risks seem to be missing. The asymmetrical funnel plot indicates a potential publication bias (Figure 2) [Sterne 2004] and also shows evidence of a small study effect (root MSE of 1.62 (p=0.04)) (Figure 3).

2.5. Discussion and conclusions

This systematic review has found evidence for an association between non-neutral wrist posture in extension or flexion and work-related CTS. The overall risk of CTS was twice that in workers exposed to non-neutral postures compared to controls. The level of evidence was tested by examining (1) the heterogeneity of the identified studies, (2) the pooled RR analysis, (3) the pattern of the forest plot, (4) the shape of the funnel plot for publication bias, and (5) Egger's test for small study effects. Overall, the findings were consistent and the effect sizes moderate.

These findings match previous reviews that found more than a 2-fold increased risk of CTS among workers working under non-neutral wrist posture for prolonged time during the workday. (Palmer et al 2007; van Rijn 2009; Barcenilla et al 2012) New studies have been published since the NIOSH review in 1997, which, if incorporated into a repeated review process today, would likely change the conclusions of the NIOSH review to include a positive association with wrist posture.

Several limitations to our review should be noted. None of the studies reviewed were prospective in design. In four studies, exposure assessment was based on worker recollection of wrist posture, and. therefore, there may be recall bias. Exposure recall bias is likely to bias the findings away from the null because cases may have formed opinions about wrist posture and their CTS. However, a review examined the extent of recall bias for exposure assessment, considering different interviewing techniques, study protocols, and questionnaire designs, and reported limited evidence of recall bias. [Coughlin1990] Differences in CTS case definitions are a potential limitation. Marras et al. and English et al. identified CTS cases from the OSHA[3] log while other studies used the case definition of an abnormal electrophysiology test and symptoms in the median nerve distribution of the hand. It is possible that use of the OSHA log would lead to more cases than expected due to over-diagnosis.

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[3] Occupational Safety and Health administration

The reviewed studies also used different methods for wrist posture assessment and different thresholds for high exposure and low exposure. Among the nine studies, four studies defined the exposed group as “deviated (twisted), extended, or flexed (bended) wrist angle” in categorical format (e.g., Yes, No). Two studies used specific wrist angles to define exposure groups (for flexion and extension > 45˚, 15˚- 45˚; for ulnar deviation > 45˚; or for radial deviation >30˚). Two studies defined exposure groups based on the self-reported time that was spent performing work with the wrist in extension or flexion. Another limitation may be the effect of confounding exposure factors. In at least one study (Osorio et al. 1994), non-neutral wrist posture was combined with forceful work in the high exposure group; therefore, wrist posture was not examined as an independent variable. It is not clear how exposure misclassification differed between methods, but it is likely that misclassification was not systematic and would, therefore, bias toward the null.

Overall, the studies reviewed provide evidence of an association between non-neutral wrist posture in extension/flexion and CTS. Future studies should evaluate this risk employing prospective study designs with exposure measurement at the individual level considering both posture deviation from neutral and duration of non-neutral posture over the work-day. In order to reduce the risk for CTS among workers who perform hand intensive tasks, employers should consider job and tool modifications and employee education that reduce the duration of exposure to non-neutral wrist postures.

Conflict of interest

No conflicts.

Acknowledgments

We would like to thank Dr. Craig Steinmaus for his support with the statistical analysis.

Table 2 Inclusion and exclusion criteria for study selection.

Inclusion	Exclusion
Study design: Case-control, cross sectional, cohort	Anecdotes or case series
Participants: Workers	Unadjusted by age or gender
Outcome: CTS (Measure of effect: OR, RR)	Missing RR, CI
Adjusted by age/gender	
Measure of exposure to wrist posture	
Published after 1980	
Article in English	

Table 3 Studies included in the meta-analysis.

Study	Type	Case Definition for CTS	Types of industry or occupation
Barnhat 1991	CS	Electrophysiologic study, physical examination criteria and symptoms.	Ski manufacturing
de Krom 1990	CC	Electrophysiologic study and symptoms (≧ twice/week)	Industry plant workers (Reference group: general population)
de Krom2 1990	CC	Electrophysiologic study and symptoms (≧ twice/week)	Industry plant workers (Reference group: general population)
English 1995	CC	Diagnosed as CTS case	Various occupations
Feldman 1987	CS	Electrophysiologic study, symptoms and physical examination (Sensation, finger grip, strength of Thenar muscle).	Electronic assembly workers
Marras 1993	CS	Determined by US OSHA 200 log (Diagnosed high risk group)	Industrial plant workers
Moore 1994	CS	Electrophysiologic study and symptoms (from US OSHA logs and employee medical records)	Pork processing plant workers
Osorio 1994	CS	Electrophysiologic study or CTS symptoms,	Grocery store workers
Tanaka 1995	CS	Symptoms; diagnosed as CTS case	Industry plant workers

Type: CS: Cross sectional study CC: Case-control study.
Physical examination criteria: Phalen’s sign or Tinel’s sign.
Symptoms: Numbness, tingling, burning in digits 1, 2 or 3.

Table 4 Method of exposure assessment by study.

Study	Exposure assessment method	Definition of exposed group
Barnhart 1991	Job classification based on provided job list from the company.	Exposed group: Flexion, extension, or ulnar deviation > 45˚ or radial deviation >30˚ (including repetitive movement, reference group: non repetitive job group)
deKrom 1990	Self reported questionnaire	Exposed: Extended wrist angle 20-40 Hours/week Reference: 0 hours/week
		Exposed: Flexed wrist angle 20-40 Hours/week Reference: 0 hours/week
English 1995	Self reported questionnaire	Awkward wrist postures (Yes / No)
Feldman 1987	Self-reported questionnaire, video analysis confirmation (two random subjects among high risk work group)	Neutral, Extension or Flexion : > 45˚, 15˚-45˚
Marras 1993	Measurement of wrist motions: position, angular velocity of movement, and angular acceleration (goniometer)	Extension or Flexion (high risk vs. low risk group: Dichotomized as a function of incidence risk)
Moore 1994	Observation (video analysis)	Hazardous job vs. safe job (force, wrist position, grip and pace of work)
Osorio 1994	Job classification (categories are ranked by CTS risk factors)	Wrist flexion/extension combined with high grasping force and repetition (Reference group: Repeated wrist flexion)
Tanaka 1995	Self reported job title.	Bending/ twisting hand or wrist (Yes/No)

Table 5 Summary showing individual studies and RR for the risk of CTS for the high risk wrist angle group.

Study	RR	95% LCI	95% UCI	N	Effect size	[95% LCI]	[95% UCI]	% Weight
Barnhart 1991	3.95	1.00	15.80	173	3.94	1.00	15.52	1.96
deKrom 1990	5.40	1.10	27.40	629	5.42	1.09	27.04	1.43
deKrom2 1990	8.70	3.10	24.10	629	8.67	3.13	24.03	3.55
English 1995	1.80	1.20	2.80	1167	1.80	1.17	2.78	19.83
Feldman 1987	2.26	1.40	4.46	586	2.27	1.26	4.09	10.66
Marras 1993	1.30	1.00	1.70	40	1.30	0.99	1.71	48.96
Moore 1994	2.80	0.20	36.70	230	2.80	0.21	37.97	0.54
Osorio 1994	6.70	0.80	52.90	56	6.69	0.82	54.44	0.84
Tanaka 1995	5.90	3.40	10.20	127M	5.87	3.39	10.16	12.24
Pooled result	2.01	-	-	-	-	1.66	2.43	100.00

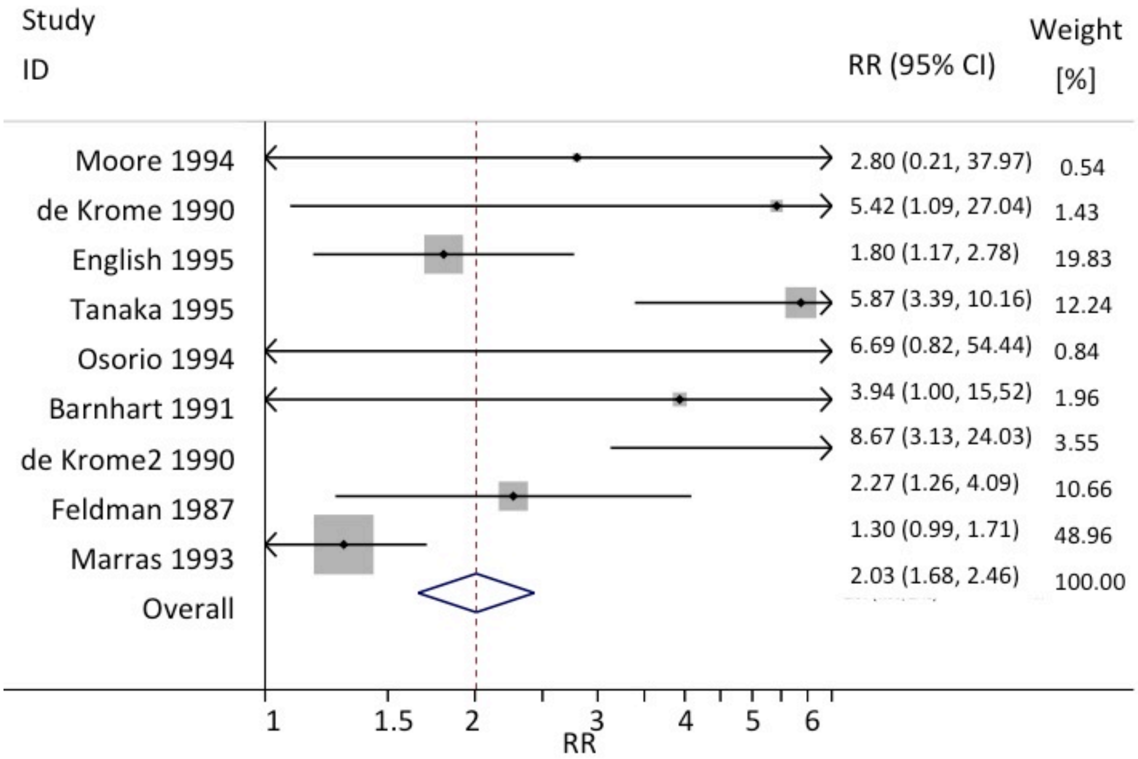

Figure 2 A Forest plot of nine studies. The meta-analysis shows a two fold increase of CTS risk among workers of the risk group. Each line represents one study and horizontal lines indicate range of 95% CI. Solid circle indicates RR of the study. Statistical weight of the study is expressed by proportional size the grey boxes based on sample size. Right column shows numerical value of forest plot.

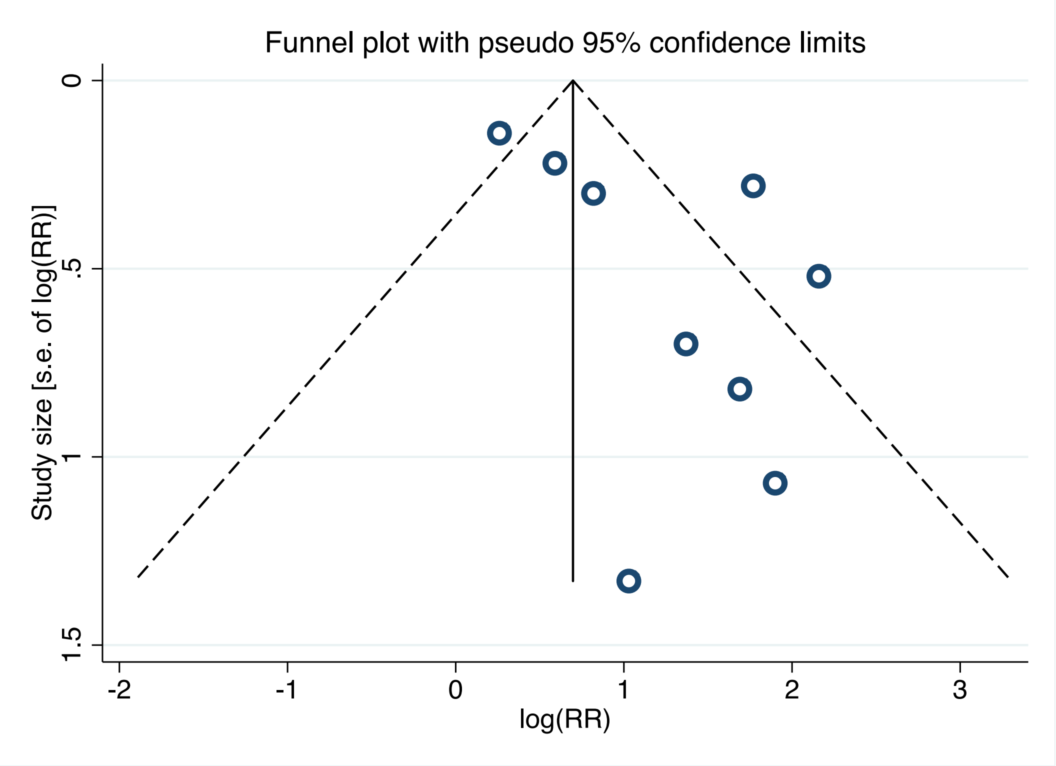

Figure 3 A funnel plot of log risk ratio (RR) of the incidence in the studies of carpal tunnel syndrome among workers is used for explorative tool to inspect publication bias. The plot shows treatment effects versus the study size that is estimated from standard error of log(RR). Open circles indicate individual studies in this meta-analysis. Dotted line is pseudo 95% confidential interval of measure of effect in the study. The asymmetrical plot indicates smaller studies with stronger effects are missing.

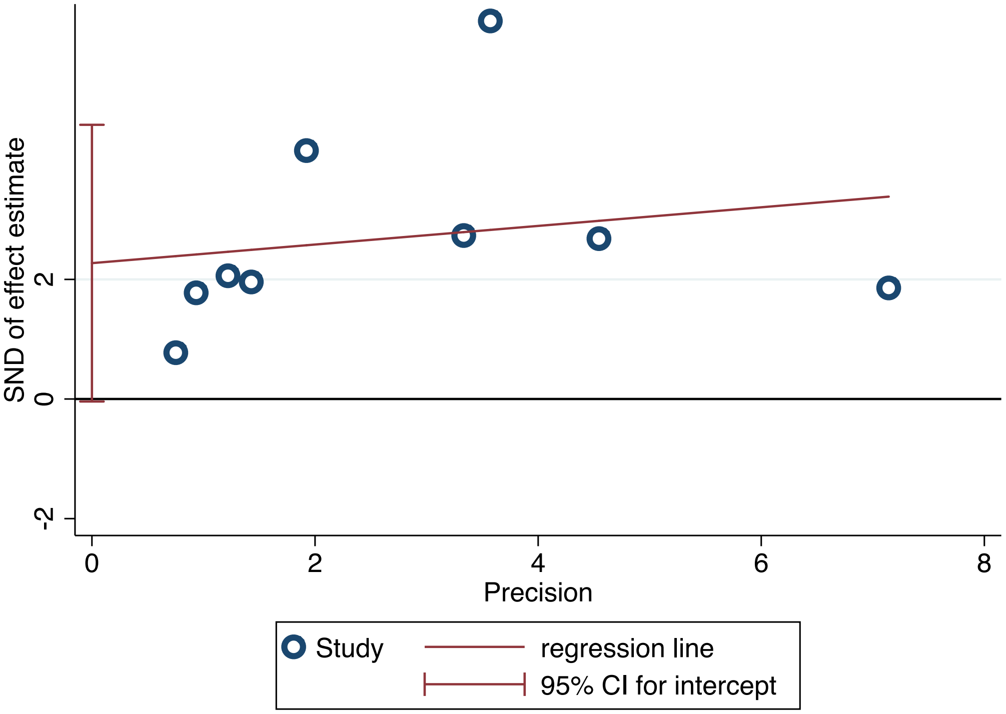

Figure 4 An Egger plot that shows regression of RR difference of each study over standard error. Precision is estimated from inverse of standard error. The intercept of regression line is suggestive for publication bias; 2.14 (SE: 0.85, p=0.04, 95%CI 0.18-4.11).

Chapter 3

3. Inter-rater reliability for wrist posture measures using video analysis

3.1. Abstract

Introduction: This study assesses the inter-rater reliability of video analysis of wrist posture measurement for workers performing hand intensive tasks. The aims of this study were to (1) develop methods for observational video analysis and (2) evaluate the effect of different posture categorization methods on reliability assessment using Kappa statistics and Interclass Correlation Coefficients (ICC).

Methods: Three raters measured wrist extension/flexion angle of 15 video frames for three predefined grip types from 10-minute videotapes of workers performing 65 different tasks. The 65 tasks analyzed were randomly selected from 333 task videos collected at four industrial sites. The hand grip for each frame of the videotapes had been previously classified into one of five grip types: no hand contact, low-force pinch, low-force power grip, high-force (>1 kg-force) pinch, or high-force (> 4 kg-force) power grip.

Results: The Kappa statistics for inter-rater reliability for wrist posture ranged between 0.48 (moderate) and 0.64 (substantial) across the grip types. The ICC ranged from 0.57 and 0.67 with the highest correlation for high-force power grip.

Discussion and Conclusions: While there was some variability in inter-rater reliability for wrist posture measurement by grip type, overall, the reliability was moderate to high. The reliability was greatest for the high-risk types of grip: high-force pinch and high-force power grip. Recommendations are made for video analysis methods of wrist posture for hand intensive work.

Keywords: Reliability, wrist posture measurement

3.2. Introduction

Wrist angle should be considered when predicting work-place risk for upper extremity musculoskeletal disorders such as carpal tunnel syndrome (CTS) and wrist or elbow tendinosis (NIOSH, 1997; Bao et al., 2006; van Rinj et al., 2009). Increasing wrist deviation from neutral is associated with increased carpal tunnel pressure, which may increase the risk for CTS (Keir et al., 2007; Holmes et al., 2011). Petit reported a two fold increase in risk for those with de Quervain's disease from repeated or sustained wrist bending in extreme posture (Petit et al., 2011). Other studies have identified non-neutral wrist postures as a risk factor for wrist tendinosis (Luopajarvi et al., 1979; Kuorinaka and Koskinen, 1979; Roto and Kivi, 1984; Amano et al., 1988; McCormack et al., 1990; Kurppa et al., 1991; Bystrom et al., 1995). Thus, measuring wrist posture for hand intensive work and using this data to modify tools and work methods to reduce sustained posture extremes may prevent distal upper extremity musculoskeletal disorders in the workplace.

Various methods are used for estimating wrist posture including: observational, direct measurement methods and video analysis. (Juul-Kristensen et al., 1997; Hignett and McAtamney, 2000; Punnett et al., 2000). Video-based methods may be more efficient for large epidemiology studies (Spielholz et al., 2001) and previous studies have demonstrated comparable accuracy between on-site observational and video-based methods (Fransson-Hall et al., 1995). On-site observational studies of wrist posture reported subtly significant reliability of posture estimation and recommended video observation for reliable estimation (Burt and Punnett, 1999). Using video assisted analysis tools for wrist posture measurement can improve reliability (Dartt et al., 2009). Statistical methods for evaluating reliability of posture measurements depend on the characteristics and distribution of data. A number of epidemiological studies have classified wrist posture among workers using categorical criteria with different angle categorization intervals (McAtamney & Corlett, 1993; Fransson-Hall et al., 1995; Juul-Kristensen et al., 1997). A prior study reported result of upper body posture estimation and reported poor to moderate reliability of wrist posture estimation between raters using the Kappa statistic (Burt and Punnett, 1999). Bao reported the impact of different categorization systems on reliability calculation with three different categorization systems (predefined posture categorization, split by 10^o, or split by 30^o) (Bao et al., 2009).

The purpose of this study was to develop methods for measurement of wrist extension/flexion posture for workers performing hand intensive production tasks by using a video analysis method and assessing the inter-rater reliability of wrist posture measurement. Inter-rater reliability was assessed for different posture categorization methods.

3.3. Method

Subjects were recruited from four industries with hand intensive jobs: milk and dairy manufacturing (site 1), chair manufacturing (site 2), mushroom packaging (site 3), and stone manufacturing (site 4). The study has been previously described (Harris et al., 2011). All subjects at the four workplaces were eligible unless they (1) had less than three months of employment, (2) were leaving within 12 months, (3) performed more than four different tasks, (4) used a forklift for more than 25% of their work time, or (5) worked on a computer for more than 25% of the work time. The study was approved by the Committee for Protection of Human Subjects at the University of California, Berkeley. Subjects signed informed consents.

Participants were videotaped, for 10 minutes, while performing the typical work of their tasks (up to four tasks per person). The videos were recorded at 30 frames per second with a camera (SONY MiniDV DCR Handycam Camcoder) on a tripod while workers performed their usual tasks. The videos were later digitized into .avi files using Adobe Premiere.

Videos of 65 of the 333 available videos were randomly selected for analysis. These videos were from 30 subjects. In a prior analysis of the videos (Harris et al., 2011), Multimedia Video Task Analysis (MVTA, Yen and Radwin, 1995) was used to categorize each video frame into one of five different grip types for each hand (Figure 1). The five grip types were: high-force power grip, high-force pinch, low-force power grip, low-force pinch, and no grip (no finger or palm load). A program was used to randomly sample 15 frames of all of the frames with high-force pinch, 15 frames of all with high-force power grip, and 15 of the frames of the three other grip types (e.g., “All Other Grips”). Frames were sampled for the subject’s dominant hand. Therefore, a total of 45 frames were evaluated for each of the 65 task videos.

Wrist angle measurement: Analysts measured dominant hand wrist extension/flexion angle for each selected video frame into 10^{o} bins from 80^{o} in extension to -70^{o} in flexion (negative sign denoting flexion) (Bao et al., 2007). Pictures of the wrist in different postures of extension/flexion, ranging from 80° to −70°, were prepared in a chart prior to video analysis, posted on the wall, and used as a visual reference guide by the analysts (Figure 2).

Video analysts training: Analysts were trained on the MVTA software, wrist posture comparison chart, and quality rating. During the training, for clear orthogonal views, the analyst measures were compared to posture collected using the MVTA angle measurement tool. Analysts passed the training after demonstrating consistent ability to measure posture within the ± 5° and after the measured wrist angles for five randomly selected task videos achieved over 80% agreement with the other raters.

Posture quality ratings: A rating system was developed to rate the quality of wrist posture measurement for each selected video frame. Every frame was rated as: clear orthogonal view, clear non-orthogonal view, ambiguous view, poor view, and non-visible view. For a frame with a clear orthogonal view, where the hand-wrist-forearm could be viewed from the radial or ulnar side, the analyst used MVTA's angle measuring tool by placing two lines, one parallel to the extensor surface of the forearm and on to the extensor surface of the hand. For frames with a clear but non-orthogonal view, an ambiguous view or a poor view, analysts made a measurement using the comparison chart. They could also examine a few video frames before and after the selected frame to help with the measurement. For frames where the hand-wrist-elbow was not visible, the analysts examined the five frames on either side of the selected frame and if the wrists were visible, used the new frame. If the wrists were still not visible, then the selected frame was marked as excluded.

Analyst cross-check meetings: Video analysts met once a week to discuss approaches for evaluating frames of poor view quality in order to improve posture measurement methods.

Statistical analysis: For the Kappa reliability analysis, wrist angles for a task video-grip type were grouped into three categories: $>30^{o}$ of flexion, $\leqq 30^{o}$ of flexion to $<50^{o}$ of extension, and $\geqq 50^{o}$ of extension based on categories used in other studies (Moore and Garg, 1995). Posture was also summarized into two categories of more or less than 30^{o} of wrist extension (Armstrong et al., 1982; Stetson et al 1991; McAtamney and Corlett, 1993; Burt and Punnett, 1999; Spielholz et al., 2011). For the ICC evaluation, the binned wrist postures were treated as continuous values. Kappa and ICC calculations were made using STATA (Version11.0).

3.4. Results

Mean and median wrist angles by each rater for the 65 task videos by grip type are presented in Table 6. Estimated mean wrist angles during high-force power grip were generally higher than high-force pinch or all other grip types. The median of estimated wrist angle was 15^{o} across all raters. Multiple comparison one-way ANOVA shows no significant difference of measurement among raters regarding same grip types.
View quality for wrist posture measurement by grip type is summarized in Table 7. Of the 975 frames viewed, more than 52.3% displayed moderate to clear quality views. The quality was so poor for less than 25% of frames that wrist posture could not be estimated. Most of these exclusions were due to wrist not being visible due to an obstruction. Figure 3 shows the distribution of wrist angle by grip types. Wrist extension occurred more often than wrist flexion.

The Kappa values across the three raters ranged from 0.48 to 0.64 and are presented by grip type in Table 8. The statistical significance of Kappa value variation was not calculated because the Kappa value itself addresses comparison of inter-group variance. Slight variation of the Kappa values among the four trichotomization methods (less than, between, more than the cutoff points of ±15º, ±20º, ±30º, -30º &50º) were observed. The high-force power grip posture measurement had the highest reliability for a specific grip type from all three raters. In general, Kappa values for wrist posture measurement during high-force pinch were lower than the Kappa values from all grip types, while using ±20º or ±30º cut-points, and were higher than all grip types when using ±15º, -30º and 50º for trichotomization cut off points. However, both Kappa values from high-force pinch and all types of grip were between 0.48 and 0.59, which fall into the same category of moderate reliability.

The average Kappa coefficient across different rating systems is 0.53 in high-force pinch and 0.52 for all grip types, which is a "moderate" reliability category. The highest reliability (average: 0.60) for wrist posture measurement occurred during high-force grips. Across the grip types, the rating system with ±20°, ±30° cut-point had the reliability (0.53), followed by ± 15º (0.52), and -30° to 50°(0.50) system. The ICC values between raters ranged from 0.57 from 0.67 across grips (Table 8). These values for overall ICC for each grip type were between moderate (0.4 and 0.6) and highly (0.6 and 0.8) matched. Similar to the Kappa analysis, the reliability of wrist angle measurement was greater for high-force pinch than for other grip types.

3.5. Discussion and conclusions

Overall, the Kappa and ICC analyses demonstrate that, with the methods used for estimating wrist extension/flexion from videos, there was moderate to high inter-rater reliability. This level of reliability is higher than that reported by others (Burt and Punnet, 1999; Bao et al., 2009; Dartt et al., 2009). There were minor differences in reliability based on grip type with slightly greater reliability for low-force grip (the combined low force pinch, low force power, and no grip) and high-force power grip compared to high-force pinch grip.

The small differences in reliability between the different three category groupings are likely to be due to how the data is distributed, especially near the cut-points. If more data are clustered near the cut-points, the reliability may be less. Overall, there was little difference in reliability based on wrist posture grouping categories.

The wrist angle was in slightly greater extension for high-force power grip than for other grip types (Table 6). The most neutral wrist angle was the no grip posture. These findings are similar to those in other studies. (O'Driscoll et al., 1992; Hansson et al., 1996, 2004; Balogh et al., 2009).

Previous studies have reported good reliability of posture measurement when evaluating large body parts. Kappa statistics greater than 0.6 were reported using posture categorization systems with wide categories for back, leg, and head postures using OWAS (Ovako Working Posture Analysing System) (de Bruijn et al., 1998) or PATH (Posture, Activity, Tools and Handling) (Pan et al., 1999).

Prior studies for estimating posture for a small joint, like the wrist, have not reported good reliability. Bao et al. (2009) conducted a reliability study, similar to ours, that involved seven raters (three lab technicians and four experienced ergonomists) viewing 37–38 randomly sampled video frames from 15 minutes of video for four different jobs. Raters evaluated joint angles for 20 different body parts. For right wrist flexion/extension, the ICC was 0.35; less than our mean ICC of 0.67. The differences between studies may be due to differences in training and analyses. They used videos from two cameras whereas our study used video from just one camera. This led to less missing data for the Bao study, approximately 4% compared to our 23%. Raters in our study had repeated trainings and meetings and used a visual reference guide with multiple pictures of the wrist in postures that differed by 10 degrees. Technicians in the Bao study estimated wrist angle on the computer using a continuous scale. In addition, the jobs analyzed were different; they studied laundry, lumber, assembly, and pharmacy jobs. Finally, the distribution of wrist postures were different between studies; their median wrist angles ranged from 2 to 9 degrees extension while ours was 15 degrees extension. The distribution of wrist posture can influence reliability.

Another reliability study of estimating wrist extension/flexion reported Kappa statistics for right wrist flexion and extension of 0.00 and −0.04, respectively (Burt and Punnett, 1999). These are “poor” levels of reliability according to Landis and Koch’s definition (Landis and Koch, 1997). This was a field study of 70 automotive manufacturing jobs observed by two technicians. They observed each job for 15 to 20 minutes during which 18 different body postures were recorded. For some joint angles, the Kappa value was high; the highest was 0.55 for left wrist extension. For the wrist, the posture was recorded in four categories: extension, 0-45 degrees or > 45 degrees or flexion, 0-30 degrees or > 30 degrees. The poor reliability for the right wrist may have been due to differences between observing wrist posture in the field versus video analysis. Another difference was that very few of the jobs were noted to involve any right wrist flexion or extension.

Some limitations should be noted in our study methods. A video based method for posture measurement has inherent limitations such as parallax, non-orthogonal views, and missing views (Ulin and Armstrong, 1992; Burt and Punnet, 1999; Bao et al., 2009; Dartt et al., 2009). However, the intended accuracy of posture measurement, in our case ± 5 degrees, could be achieved with training and careful video collection and analysis. Our analysis was based on evaluating 45 randomly sampled frames on a 10-minute task-video (15 frames for each grip type). While the brief 10-minute video of the task could lead to some exposure misclassification (Mathiassen et al., 2012), the method used will not effect inter-rater reliability assessment because reviewers reviewed the same 15 frames. In conclusion, wrist angle measurement had moderate to good inter-rater reliability, across grip types, when using the video collection procedures, training of raters and analysis methods presented. During filming, to the extent possible, the camera view should be orthogonal to the posture to be measured and the field of view should include the arm from elbow to fingers. This may be difficult to do for tasks where the worker walks or twists their torso. In these cases, it may be better not to use a moving camera but to have one or two cameras set on tripods in fixed locations relative to the worker. For video analyses, raters should be trained with clear guidelines and provided with reference pictures of wrist postures at 10 degrees increments. Posture angles can be estimated from a random sampling of video frames, selection based on hand grip type (e.g., high force power grip, high force pinch grip and low force grips). Raters should meet with other raters on a regular basis to discuss difficult-tointerpret videos. Novice raters achieved a good level of reliability within 30 hours of training (e.g., 20 tasks videos, each 1.5 hours). These recommendations are similar to those in other papers that present methods for observer ratings from videos (Ulin and Armstrong, 1992).

Acknowledgments

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Angle = 131.630 degrees

Figure 5 Screen capture during video analysis of wrist angle using MVTA. The yellow lines are placed by analysts on the following landmarks: Olecranon, styloid process of Ulna and dorsal surface of the hand.

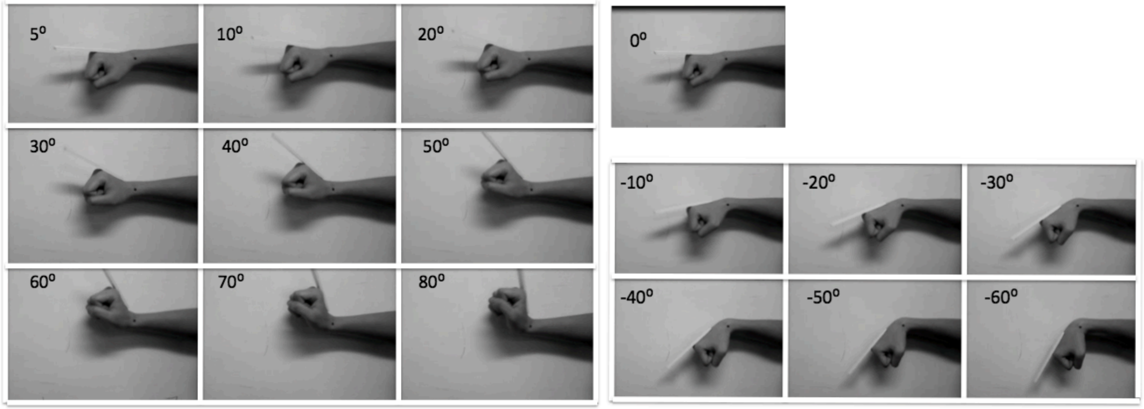

Figure 6 Reference picture of wrist postures used by raters during video analysis. Wrist extension is positive and flexion is negative.

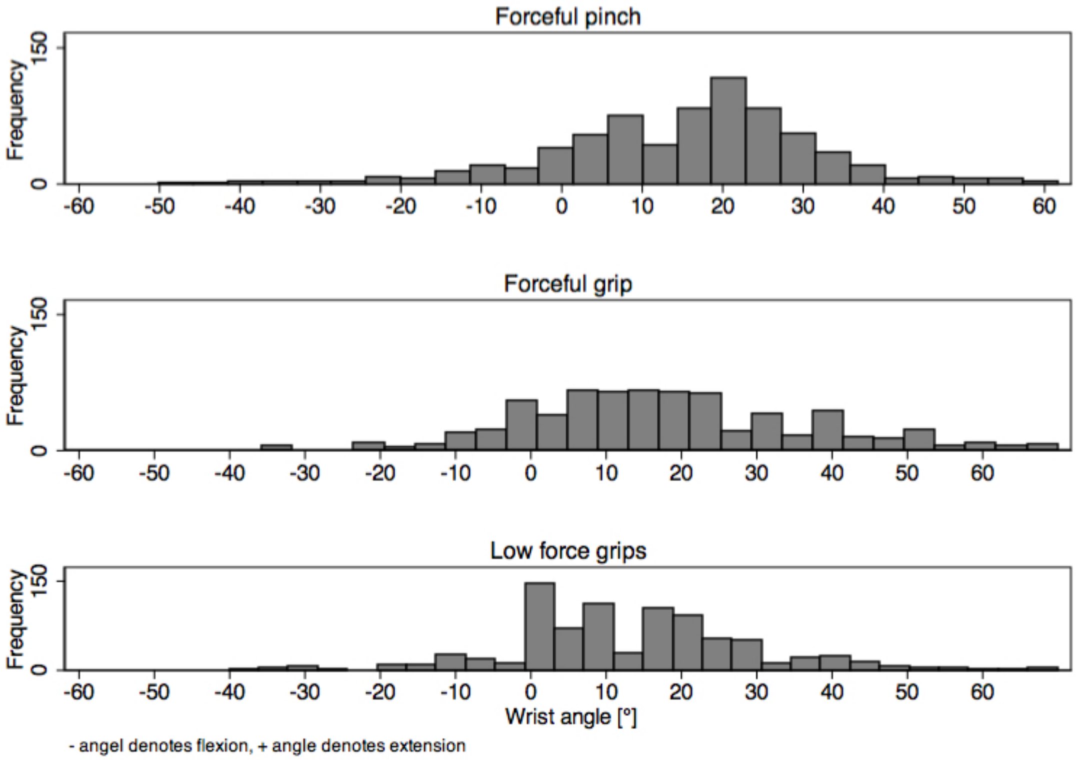

Figure 7 Histogram distributions of wrist angle by grip type using average value for the frame across the 3 analysts (forceful pinch = 707 frames; forceful grip =677 frames; others grips = 820 frames)

Table 6 Mean and median wrist angle by rater for 65 task videos and grip types. All grip types include high-force pinch, high-force power grip, low-force pinch, low-force power grip, and no gripping posture.

		High-force pinch	**High-force power grip**	**Low-force pinch**	**Low-force power grip**	**No grips**	**All grips**
Rater A	Median	15.00	15.00	20.00	15.00	5.00	15.00
	Mean (SD)	15.92 (17.77)	17.65 (21.13)	17.88 (16.13)	14.21 (18.86)	8.20 (14.81)	15.35 (15.05)
Rater B	Median	20.00	20.00	20.00	15.00	5.00	15.00
	Mean (SD)	15.18 (15.18)	19.43 (20.64)	16.53 (15.46)	14.42 (17.23)	7.98 (11.93)	15.09 (13.51)
Rater C	Median	20.00	15.00	20.00	15.00	5.00	15.00
	Mean (SD)	16.80 (16.77)	18.49 (20.20)	17.47 (14.55)	14.15 (18.02)	8.37 (12.82)	15.86 (13.74)
Across raters	Mean (SD)	15.76 (15.62)	18.43 (18.55)	16.88 (14.16)	15.84 (16.36)	8.38 (11.59)	15.36 (12.68)

Table 7 Mean percent of frames within a column (grip type) by quality of view rating. Low force grips* includes low force pinch, low force grip, and no grip.

Quality Rating	High force pinch	High force power grip	Low force grips*	All grips
1. Clear orthogonal View	3.0%	1.4%	1.2%	2.1%
2. Clear view but not directly measurable	15.9%	16.1%	23.5%	18.1%
3. Moderate view	41.1%	34.8%	40.2%	39.4%
4. Partial view and difficult to estimate	15.3%	21.8%	12.6%	16.0%
5. No view	23.5%	22.3%	22.5%	22.9%

Table 8 Summary of Kappa coefficients and ICC with 95% CI: Wrist angle data are split by three categories, e.g., less than -15°, -15° to 15°, more than 15°. "–" denotes wrist flexion and "+" extension. Summary of ICC values by grip type was estimated across wrist angles from 60° flexion to 80° extension with 10° intervals. [N = 65 task-videos].

	High-force pinch grip	**High-force power grip**	**Low-force grips**	**All grips**
Three category cut-points		Kappa scores		
-15°, 15°	0.59	0.64	0.59	0.52
-20°, 20°	0.50	0.63	0.58	0.53
-30°, 30°	0.48	0.62	0.72	0.53
-30°, 50°	0.54	0.50	0.65	0.50
Mean (SD)	0.53 (0.05)	0.60 (0.07)	0.64 (0.06)	0.52 (0.01)
		ICC (95% CI)		
	0.63 (0.43-0.82)	0.67 (0.43-0.91)	0.57 (0.41-0.92)	0.67 (0.42-0.71)

Table 9 Cut points for wrist flexion-extension angle used for categorization in other studies. Other kinds of pre-defined posture measurement systems without wrist posture criterion are not included in this table (COWAS, OWAS, PATH, TRAC,VIRA) RULA†:Rapid Upper Limb Assessment.

Study	Cut-off point of posture categorization system
Jay et al., 2013	<-30º, -30º to 50º, ≥50º
Bao et al., 2009	<−45º, −45º to −15º, −15º to 15º, 15º to 45º, ≥45º
Burt and Punnett 1999	<-30º, -30º to 0º, 0º to 45º, ≥45º
Genaidy and Kawarowski 1993	<-45º, -45º to -15º, -15º to 15º, 15º to 45º, ≥45º
McAtamney and Corlett 1993 (RULA†)	<-15º, -15º to 0º, 0º to 15º, ≥15º
Armstrong et al., 1982	<-50º, -50º to -25º, -25º to -10º, 10º to 40º, ≥ 40º

Chapter 4

4. Wrist posture and risk of carpal tunnel syndrome among blue-collar workers

4.1. Abstract

Objective: Carpal Tunnel Syndrome (CTS) is a common work-related nerve entrapment. Many studied has been conducted to identify risk factors of CTS, but the contribution of postural risk has not been as well characterized as other risk factors. This prospective epidemiological study assessed the association between CTS and exposure to non-neutral wrist posture among blue-collar workers.

Method: Employees (N=447) from four industrial sites in the U.S. were followed for up to 28 months with symptom and work questionnaires every four months and nerve conduction studies at the wrist to identify incident cases of CTS. Workers with CTS at baseline were excluded from the subsequent analysis. Wrist posture was estimated from videos of each worker's tasks. A time-weighted average (TWA) of the wrist angle was calculated for each worker based on self-estimated hours worked on each task per week. A survival analysis was conducted using a hazard model to examine association between wrist posture and incident CTS cases while controlling for covariates.

Results: During the 28 months of follow-up, there were 29 incident cases of dominant side CTS. Univariate and multivariable analysis indicated that CTS hazard ratio (HR) increased over two-fold with exposure to the combination of **wrist extension and forceful pinch.** The HR, adjusted for age, gender, BMI, and medical conditions, was 2.83 (95% CI: 0.91-8.76; P-value <0.2), where the cut-point between high and low wrist extension was a TWA of 6.07 degrees. TWA of peak wrist flexion was negatively associated with CTS (adjusted HR = 0.40 (95% CI: 0.12-1.27; p-value <0.1).

Conclusion: The findings of this study suggest that preventing wrist extension or a combination of wrist extension and forceful pinching may reduce the risk of CTS among blue-collar production workers who perform hand intensive jobs. These findings might be useful in the design of industrial workplace safety programs in order to keep workers healthy and productive.

4. 2. Introduction

Carpal Tunnel Syndrome (CTS) is the one of most prevalent work-related peripheral neuropathies among blue-collar workers who perform hand-intensive tasks. CTS is a median nerve entrapment at the wrist which causes sensory loss in the median nerve innervating the fingers (thumb, index finger, middle finger, and half of the ring finger) and weakness of a thumb thenar muscle. (de Krome et al 1992; Phalen 1996; Maghsoudipour 2008) Typical symptoms of CTS are tingling, numbness, and burning pain. CTS can cause reduced motor control and strength of pinch force and, may lead to dropping tools or parts or reduced efficiency of hand related tasks. Therefore, CTS can lead to disability, carpal tunnel release surgery, rehabilitation, and job change. (Turner 2004) According to BLS data, there were 10,300 incidents of work-related CTS in 2011 in the US; however, this is likely to be a significant underestimation. (BLS2013) Other data sources suggest that there are approximately 450,000 workers who received carpal tunnel release surgery annually at a cost of 2 billion US dollars. (Luckhaupt 2010; Dale 2013)

The primarily biomechanical risk factors for CTS are forceful hand tasks, repetitive wrist motion, and sustained awkward wrist postures. (Roquelaure et al 1997 ; NIOSH 1998; Viikari-Juntura and Silverstein 1999; Fagarasanu & Kumar 2003; Violante et al 2007; Roquelaure et al 2008) In a case-control study, Roquelaure observed that a repeated forceful task, which requires more than 1 kg of grip force, is associated with CTS (OR: 9.0) as are task requiring repetitive hand exertions with short elementary cycles (less than 10 s/task; OR:8.8). (Roquelaure et al 1997) One of the few longitudinal studies reported that an increased risk of CTS can be predicted by applied peak force level when force level exceeds than the recommended TLV. (Gell et al 2005; Werner et al 2005)

However, unlike these relatively well-established biomechanical risk factors, the associations between awkward wrist postures and CTS are not well known.
There are few studies that assess wrist posture with accuracy or at the individual worker level and very few studies that are of prospective design. Thus, the specific aim of this study is to use data collected during a prospective study of production workers and identify associations between wrist extension and flexion and incident CTS.

4. 3. Methods

This study used previously collected data from a 2-year prospective cohort study of 450 workers between the 18-70 years of age. Workers were from four different labor-intensive production company sites (1) milk and dairy manufacturing, (2) chair manufacturing, (3) mushroom packing, and (4) stone manufacturing. The cohort data collection was conducted from 2005 to 2007. (Adamson-Harris 2013) Subjects were included if they worked in manufacturing/production jobs that involved varying levels of exposure to hand tasks. Subjects were excluded from the study if they (1) performed more than four primary tasks, (2) were employed for less than three months, (3) were planning to leave the job within 12 months, (4) drove a forklift for more than 25 percent of the work time, or (5) did computer-related office work for more than 25 percent of the work time. Subjects with CTS at baseline were excluded from subsequent analysis because they were not eligible to become a new case. The study was approved by the University of California Berkeley Committee for the Protection of Human Subjects and each workers signed an informed consent.

Baseline data were collected by questionnaire and median nerve conduction test. A baseline questionnaire was administered in the subjects' primary language on demographics, medical history, work history, and job demands (e.g., Job Strain Index). A symptom and job questionnaire was administered every 4 months. The nerve conduction tests were carried out by a previous researcher who was blinded to workplace exposures. The nerve conduction test for CTS was performed on all subjects at baseline and annually and when new symptoms consistent with CTS were reported on the symptom questionnaire.

The CTS case definition used was (i) the presence of paresthesia (numbness, tingling, burning, or pain) in fingers of the hand median nerve distribution (one or more of the first three digits) for the past 7 days[4] and (ii) an abnormal median nerve conduction test result that is consistent with CTS[5].

The study recorded participant's routine tasks at the worksite using a SONY MiniDV Handycam Camcorder (DCR model). The subject's upper body was recorded for at least 15 minutes for each task (up to 4 tasks). The recorded video clips were digitized into AVI format files using Adobe Premiere 6.0 for exposure analysis in the laboratory. The videos were recorded at a frequency of 30 frames per second. In a previous force analysis study, Multimedia Video Task Analysis (MVTA) program was used to categorize all video frames into one of 5 different grip types for each hand. Three hundred thirty-three video clips of tasks were analyzed. They were classified into 49 different jobs encompassing a total of 166 different tasks. Three raters utilized MVTA for the measurement of each subject wrist angle.

The video frames for each task were categorized into five hand posture categories for

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[4] Symptoms were collected every 4 months by questionnaire.

[5] Sensory latency > 3.5 msec at 14 cm, or motor latency > 4.5 msec, or more than 0.5 msec of difference between ulnar and median nerve latency across the wrist.

each hand: low force pinch[6], high force pinch[7], low force power grip[8], high force power grip[9], no grip. The thresholds of 1 kg pinch and 4 kg power grip were selected for the thresholds for 'high force' based on a previous study of observational analysis of the hand and wrist. (Bao et al 2007) A rater estimated the angle of the dominant hand wrist extension/flexion on 45 randomly sampled frames[10] for each task-video: 15 video frames were sampled from the frames classified as high-force pinch, 15 frames from frames of high-force power grip, and 15 frames from all other grip types (e.g., low-force pinch, light grip and no grip). Wrist angles are expressed as + sign for extension, − sign for flexion, and 0° for the anatomical neutral position. The absolute value of the wrist angle is used to express the number of degrees of deviation in wrist extension/flexion angle from the anatomical neutral posture. The median wrist angle for each task is estimated from measurements from 15 frames of video for each of three grip types. These three grip types are then normalized by length of recorded video time to estimate wrist angle for the task. Wrist angles of 190 subjects were estimated from the task-videos. For subjects without videos of their tasks (N=260), their wrist angle per task was imputed using the median wrist angle from the other subjects who performed the same task and had video data [11]. (Arnold 2003; Sterne et al 2009; Harris et al 2011)

The Time Weighted Average (TWA) of wrist angle for each worker is estimated using the worker reported weekly work time for each task. The approach to calculating the TWA follows the NIOSH guidelines on accumulated noise risk assessment along weekly working hours. [NIOSH 2008] For example, the TWA wrist deviation from neutral for high-force power grip or pinch was calculated using the following equation:

$$\text{TWA} = \sum_{i=1}^{4}\left\{\frac{\sum_{j=1}^{5}\bar{a}_{ij} * vt_{ij}}{\sum_{j=1}^{5} vt_{ij}}\right\} * wt_i$$

Where *i* is the task number (1 to 4); j is grip type where j =1 (high-force pinch), j=2 (high-force grip), j=3 (low-force pinch), j=4 (low-force power grip), and j=5 (no load grip); ā= mean absolute wrist angle and calculated as $\frac{\sum_{n=1}^{15}|a_n|}{15}$ and a_n is the wrist angle value from the *n*th video frame of 15; vt_{ij} is the duration of the video that is the *j*th grip type; and t_i is the weekly hours of the *i*th task; *w* is the total hours worked in a week.

Survival analysis was used to compute the hazard ratio (HR) for incident case analysis. Variables were tested in the multivariable models if, at the univariate level, the p-value was less than 0.20. Potential confounders were tested in a multivariable model if they were not highly correlated (r<0.3) with the tested exposure variables and these variables were retained in the final model if their presence changed the HR by more than 10%.

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[6] Less than 1 kg of force

[7] Over than 1 kg of force

[8] Less than 4 kg of force

[9] Over than 4 kg of force

[10] An Excel macro designed to select 15 frames at random for each of the category.

[11] Task code is collected from interview and confirmed during the field assessment.

4. 4. Results

4.4.1. Descriptive

Table 10 shows the demographics of the study population. The participants included 447 active workers (286 male, 161 female) from four different work sites. The average age was 38.64 years (SD=11. 16) and average BMI was 28.73 (SD=4.68). Forty-one (9.2%) reported a physician diagnosed medical condition (e.g. rheumatoid arthritis, diabetes, thyroid, pregnancy.) Smoking was reported by 31.6% of the participants and 61.7% reported more than 3 years of working history at their job. The participants were largely Hispanic (83.29%). Table 11 presents descriptive statistics of the physical exposure measurements. Deviated angle from neutral wrist posture was estimated and simultaneously observed with force level and duration while posing that posture.

4.4.2. Prevalence analysis

There were total 23 prevalent CTS cases at baseline. A case had to meet the case criteria at baseline but not have polyneuropathy. The OR for age over 40 years was 2.61 (95%CI: 1.05-6.47; p=0.04) and the OR for female gender was 1.15 (95%CI: 0.49-2.72; p=0.75). Being obese (BMI>=30) was associated with an OR of 3.12 (95%CI: 1.32-7.39; p=0.01) for CTS.

Having a medical condition (OR=1.52; 95%CI: 0.43-5.36), diabetes (OR=1.46; 95%CI: 0.32-6.56), previous/current smoking history (OR=1.13; 95%CI: 0.47-2.73), engaging in more than 1 hour of weekly intensive physical activity (OR=1.65; 95%CI: 0.71-3.84), poor/fair health status (OR=1.88; 95%CI: 0.56-6.28), high school or higher education (OR= 1.22; 95%CI: 0.50-2.95) were associated with an increased OR for prevalent CTS but with non-significant confidence intervals. Additionally, participants had an increased OR while working more than 1 year at their job or working on a job with high demand and low decision latitude (OR=1.66; 95%CI: 0.58-4.73).

Exposure variables were dichotomized (high and low) to achieve an equal number of prevalent CTS cases per group. Median Deviation in Flexion during Heavy-Pinch/Grip (OR 0.44; 94%CI: 0.16-1.19 p-value=0.11), Median Deviation in Extension during Heavy-Pinch/Grip (OR=0.49; 95%CI: 0.19-1.24; p-value=0.13), and Peak Deviation in Extension of any task (OR=0.54; 95%CI: 0.23-1.27; p-value=0.16) showed a relatively strong negative association with CTS prevalence. Tertile exposure variables showed Median Forceful Grip Deviation from Neutral (OR=0.68; 95%CI: 0.40-1.17; p-value=0.17), Peak Forceful Angle from Neutral (OR=0.66; 95%CI: 0.38-1.14; p-value=0.13), Median Deviation in Flexion during Heavy-Pinch/Grip (OR=0.58; 95%CI:

0.32-1.03; p-value=0.06), and Median deviation in Extension during Heavy-Pinch Grip (OR=1.71; 95%CI: 0.95-3.06; p-value=0.07).

4.4.3. Incidence analysis

Four hundred and fifteen of the 447 individuals at baseline had follow-up data for up to 28 months. Twenty-three individuals were not eligible to become incident cases because they were cases at baseline. There were 29 incident cases of dominant-hand CTS for an incidence rate of 5.17 cases per 100 person-years.

Previously known demographic risk factors for CTS were identified in the analysis of the incident CTS cases. Odds ratios were elevated for being over 40 years old, female, and obese (BMI >30) (OR=2.14; 95%CI: 0.97-4.71), 1.72 (95%CI: 0.81-3.66), 2.13 (95%CI: 1-4.53; p-value <0.2), respectively. Having a medical condition increased the OR of CTS incidence (OR=3.59; 95%CI: 1.43-9.02; p-value=0.01) and this was due primarily to diabetes (OR=3.58; 95%CI: 1.25-10.24; p-value=0.02). Previous history of distal upper extremity disorder (OR=7.67; 95%CI: 1.34-43.74; p-value=0.02) was associated with an increased CTS incidence. Additionally, the Hispanic subjects in our study population among showed a lower OR for CTS compared to other ethnic groups (OR=0.24; 95%CI: 0.09-0.62; p-value<0.05).

No significant association with incident CTS was identified for smoking history, hand intensive activity level (outside of work), education level, and job satisfaction level.

Exposure variables were dichotomized (high and low) achieved an equal number of CTS incidence cases per group (Table 11).

4.4.4. Multivariate models for incident analysis

The unadjusted and adjusted models for the physical exposure variables at work are presented in Table 12. The adjusted models all included age>40 years old, gender (female), BMI >30, and having a medical condition; these variables are historical covariates and demonstrated an association at the univariate level with CTS incidence.

Table 12 shows associations to incident CTS for each exposure variable. Wrist angle deviation from the neutral position during forceful pinch (adjusted HR 2.7; 95%CI: 0.85-8.57 P-value <0.1; cut-off point 5.88º) and high level of wrist extension posture from neutral position during forceful pinch (adjusted HR=2.83; 95%CI: 0.91-8.76; cut-off point 6.07º) were risk factors associated with incident CTS.

The HR for peak deviation in flexion or % time in extension or flexion with forceful grip were negatively associated with CTS risk. Peak deviation in flexion of any task adjusted HR was 0.40 (95%CI: 0.12-1.27; p-value <0.1; cut-off point 20º), percent time in more than 30º extension during forceful pinch HR was 0.38 (95%CI: 0.12-1.16; p-value<0.2; cut-off point 16.77%), and percent time in more than 30º flexion during forceful pinch HR was 0.24 (95%CI: 0.05-1.24; p-value <0.1; cut-off point 0.43%). A concern is the smaller sample sizes for these risk estimations and the small percentiles for time exposure.

4. 5. Discussion

4.5.1. Non occupational factors

A high BMI was a strong personal factor predicting risk of CTS in both the cross-sectional and prospective analysis. Similar associations have been reported in previous studies. (Werner et al 1994) Age over 40 years old was also a significant predictor. Likewise, female gender was identified as a risk factor for CTS, however, this result may have been related to the high prevalence of female workers performing frequent pinching from the sewing task group. Having a medical condition was also a predictive factor; however, the number of cases was too small to draw strong conclusions. Similarly, the, ethnicity of most subjects was Hispanic making it difficult to compare risk across other ethnicities.

4.5.2. Posture measures

A novel finding was the elevated hazard ratio for wrist extension and median deviation from the neutral position during forceful pinch in the final adjusted model. This relationship has not been reported in previous studies. The relationship was also observed in the analysis of prevalent cases at baseline. The somewhat lower risk among workers at baseline may due to a healthy worker effect – some workers with wrist disorders may avoid tasks that require forceful work in awkward postures. High level of exposure to only wrist extension did not increase risk, but the sample size was small for this comparison.

It was unexpected to find a significant protective relationship with CTS for peak wrist flexion or percent time in wrist flexion or extension with forceful gripping. A single peak wrist flexion posture may not reflect the average wrist posture exposures which are likely to be better estimates of risk. It is likely that the combination of wrist flexion and forceful gripping is difficult to maintain for a prolonged time. Therefore, these exposures are reduced due to the difficulty of working in that specific posture. Regardless of the forcefulness of gripping, wrist flexion itself had protective HR. The relationship was observed in the fully adjusted model.

According to these findings, CTS interventions should focus on preventing a combination of wrist extension and forceful pinching.

4.6. Limitations and future work

A potential limitation of this study is the measurement of posture from videos. The wrist angle was observed and analyzed from video clips, which occasionally were not recorded in the best angle for posture measurement. This may lead to parallax errors and non-differential misclassification of exposure, which introduces random error in all observations, and may introduce a bias towards the null hypothesis and an underestimation of risk. However, the non-differential misclassification of wrist angle can be considered as a minor limitation because the previous laboratory observation study results well matched those of the video observation method for exposure assessment. (Fransson-Hall et al 1995)

There are several possible types of residual bias in this study. To reduce the possible selection bias, we recruited subjects from various job titles that would adequately represent the targeted study population. Also, the potential bias from healthy worker survival effects was reduced by comparison among worker groups and following a substantially large cohort for a reasonable duration. In addition, the potential information bias of outcome measurement was minimized by adopting a specific CTS case definition that is widely accepted.

Further studies may include the ulnar–radial deviation or pronation–supination measurement as they may play a role in the pathophysiology of CTS.

4.7. Concluding remarks

In conclusion, this study has the following main strengths: 1) it collected quantitative workplace exposure data at the individual level, and 2) a prospective study design that reduced the potential recall bias inherent in retrospective cohort studies. Additional strengths are the substantial power of the study from the large cohort size and the variety of work tasks that covers a broad range of exposures, jobs and tasks.

This study contributes evidence toward a better understanding of postural factors at work that increase risk of CTS. Research in this area has been limited due to the lack of prospective studies with individual-level exposure assessment. Our findings may be helpful to occupational safety and health managers in the design of safety programs to prevent and accommodate work-related CTS.

Table 10 Characteristics of workers.

	n	%
Age at enrollment (447)		
< 40 years old	226	50.7%
≧ 40 years old	221	49.3%
Gender (447)		
Male	286	64.0%
Female	161	36.0%
Body mass index (441)		
< 30	288	65.3%
≧ 30 (obese)	153	34.7%
Handedness (440)		
Left	16	3.6%
Right	424	96.4%
Medical History (447)		
No Medical Condition	406	90.8%
Medical Condition	41	9.2%
Smoking Status (443)		
Never smoked	303	68.4%
Currently Smokes	67	15.1%
Previously smoked	73	16.5%
Educational Level (439)		
Some High school/less	310	70.6%
High school graduate or above	129	29.4%
Ethnicity (432)		
Hispanic	372	86.1%
Other	60	15.9%
Years on current job at enrollment (446)		
<6 months	35	7.9%
6 months to 3 years	136	30.5%
3 to 7 years	124	27.8%
7 to 15 years	110	24.7%
> 15 years	41	9.2%

Table 11. Descriptive statistics for wrist posture measures for the incident analysis. N denotes number of subjects for each exposure variable for which measurements were available. Values are in degrees except for percent. Stratification of study population was based on equal number of CTS cases in the low and high exposure group.

Exposure measurements				Group	
	N	Mean	SD	Cases (High/low)	Cut-off
Median Deviation from Neutral	389	17.16	5.68	(12/13)	15.59
Peak Deviation from Neutral	389	48.12	10.41	(11/14)	45.32
Median Deviation in Extension	389	17.36	5.81	(12/13)	16.00
Median Deviation in Flexion	370	3.67	2.49	(12/12)	3.00
Peak Deviation in Extension of any task	431	51.75	10.58	(14/14)	52.50
Peak Deviation in Flexion of any task	431	19.52	10.19	(9/19)	20.00
% Time in >=50 Extension	323	0.03	0.04	(9/9)	0.02
% Time in >=30 Extension	387	0.23	0.15	(12/13)	0.18
% Time in >=30 Flexion	288	0.01	0.02	(9/10)	0.01

Table 11 continued.

Exposure measurements				Group	
	N	Mean	SD	Cases (High/low)	Cut-off
Median Deviation from Neutral: Forceful Grip	386	20.82	7.93	(12/13)	16.32
Peak Forceful Angle from Neutral	387	44.86	11.36	(12/13)	40.50
Median Deviation from Neutral: Forceful Pinch	373	5.21	3.23	(12/12)	5.88
Peak deviation: Forceful Pinch	374	36.96	7.44	(12/12)	35.00
Median Deviation in Extension: Forceful Pinch/Grip	386	20.75	8.56	(12/13)	17.31
Median Deviation in Flexion: Forceful Pinch/Grip	358	7.67	7.97	(11/12)	4.70
Median deviation in Extension: Forceful Pinch	373	5.23	3.37	(12/12)	6.07
Median deviation in Extension: Forceful Grip	341	2.08	2.00	(9/14)	1.68
Median deviation in Flexion: Forceful Pinch	313	2.05	1.83	(10/10)	2.17
Median deviation in Flexion: Forceful Grip	206	0.89	0.83	(6/7)	0.47
% Time in >=50 Extension: Forceful Pinch/Grip	309	0.07	0.09	(8/9)	0.01
% Time in >=30 Extension: Forceful Pinch/Grip	383	0.28	0.16	(12/12)	0.17
% Time in >=30 Flexion: Forceful Pinch/Grip	269	0.04	0.09	(6/8)	0.00
% Time in >=50 Extension: Forceful Pinch	242	0.01	0.02	(7/8)	0.00
% Time in >=30 Extension: Forceful Pinch	366	0.06	0.05	(10/13)	0.06
% Time in >=30 Flexion: Forceful Pinch	240	0.01	0.01	(6/8)	0.00

Table 12. Unadjusted and adjusted hazard ratios for postural risk factors. Values are in degrees except for percent. (P-value <=0.1, * p-value<=0.2)**

	Unadjusted HR (95% CI)			Adjusted^a HR (95% CI)		
Median Deviation from Neutral	0.82	(0.29-	2.34)	0.58	(0.19-	1.76)
Peak Deviation from Neutral	1.59	(0.56-	4.46)	1.75	(0.60-	5.11)
Median Deviation in Extension	0.85	(0.30-	2.41)	0.61	(0.20-	1.81)
Median Deviation in Flexion	0.88	(0.30-	2.57)	0.56	(0.18-	1.77)
Peak Deviation in Extension of any task	1.40	(0.52-	3.76)	1.73	(0.62-	4.83)
Peak Deviation in Flexion of any task	0.38**	(0.12-	1.18)	0.40*	(0.12-	1.27)
% Time in >=50 Extension	1.44	(0.46-	4.54)	1.21	(0.36-	4.07)
% Time in >=30 Extension	0.86	(0.30-	2.45)	0.63	(0.21-	1.9)
% Time in >=30 Flexion	0.87	(0.25-	3.10)	0.79	(0.22-	2.84)

Table 12 continued,

Median Deviation from Neutral: Forceful Grip	0.62	(0.22-	1.72)	0.56	(0.19-	1.67)
Peak Forceful Angle from Neutral	1.00	(0.36-	2.75)	1.11	(0.39-	3.14)
Median Deviation from Neutral: Forceful Pinch	3.05**	(0.97-	9.61)	2.70**	(0.85-	8.57)
Peak deviation: Forceful Pinch	0.56	(0.19-	1.67)	0.53	(0.17-	1.64)
Median Deviation in Extension: Forceful Pinch/Grip	0.68	(0.25-	1.88)	0.64	(0.22-	1.91)
Median Deviation in Flexion: Forceful Pinch/Grip	0.96	(0.34-	2.71)	0.56	(0.18-	1.79)
Median deviation in Extension: Forceful Pinch	3.25**	(1.01-	10.47)	2.83	(0.91-	8.76)
Median deviation in Extension: Forceful Grip	0.56	(0.17-	1.80)	0.81	(0.22-	2.99)
Median deviation in Flexion: Forceful Pinch	1.84	(0.62-	5.48)	1.43	(0.44-	4.66)
Median deviation in Flexion: Forceful Grip	0.74	(0.18-	2.99)	0.54	(0.13-	2.28)
% Time in >=50 Extension: Forceful Pinch/Grip	0.56	(0.17-	1.82)	0.52	(0.15-	1.82)
% Time in >=30 Extension: Forceful Pinch/Grip	0.44*	(0.15-	1.26)	0.38**	(0.12-	1.16)
% Time in >=30 Flexion: Forceful Pinch/Grip	0.54	(0.14-	2.04)	0.24**	(0.05-	1.24)
% Time in >=50 Extension: Forceful Pinch	0.33*	(0.09-	1.28)	1.21	(0.36-	4.07)
% Time in >=30 Extension: Forceful Pinch	1.13	(0.36-	3.60)	0.75	(0.21-	2.62)
% Time in >=30 Flexion: Forceful Pinch	1.20	(0.32-	4.54)	0.76	(0.16-	3.61)

[a] Separate multivariable models used for each stratum of exposure measurement and adjusted for age, BMI, and medical condition.

Chapter 5

5. Conclusion

5. 1. Summary of findings

The goal of this research was to improve our understanding regarding how wrist posture is associated with CTS among blue-collar workers. Worker wrist posture can be influenced by tool and workstation design, task, and training. This research provides insight into prevention strategies for protecting workers from developing CTS. It is the first study to conduct wrist posture measurement of workers at the individual level for the assessment of CTS risk. In addition, it is the first prospective study to evaluate wrist posture risk for incident CTS cases across a variety of industrial sites and jobs.

The primary findings from each chapter are summarized below.

Chapter 2 presented a meta-analysis that summarized the findings from nine previous epidemiologic studies of CTS and postural risk. This chapter provided evidence that prolonged exposure to non-neutral wrist extension/flexion postures is associated with a two-fold increased risk for CTS compared to low hours of exposure to non-neutral wrist postures.

Chapter 3 evaluated inter-observer variability for estimating wrist extension/flexion postures among three raters. The evaluation used 65 video clips of tasks that workers performed doing their usual work. The Kappa statistics for inter-rater reliability ranged between 0.48 (moderate) to 0.64 (substantial) across the five grip types. The ICC ranged from 0.57 and 0.67. There were minor differences in inter-rater reliability for wrist posture measurement by grip type. The reliability was greatest for the high-risk types of grip: high-force pinch and high-force power grip. Overall, the reliability was moderate to high indicating that the methods for video analysis were acceptable. Recommendations were made for posture measurement for future ergonomic studies.

Chapter 4 evaluated the association between wrist posture and CTS, adjusting for demographic, work related psychosocial, and biomechanical factors. The study population was a group of workers at four industrial sites in the U.S. followed for up to 28 months (N=447). A survival analysis was conducted using a hazard model to examine relationships between exposures and CTS incidence. Wrist extension and forceful pinch posture increase risk of CTS (adjusted HR 2.83 (P-value <0.2 95% CI 0.91-8.76). Peak wrist flexion was protective with a HR value lower than 1.00 (adjusted HR 0.40, 95% CI 0.12-1.27, p-value <0.1). Recommendations are made to prevent wrist extension or a combination of wrist extension and pinching in order to reduce CTS risk among blue-collar workers in hand intensive jobs.

5. 2. Implication of findings

This dissertation found an association between CTS and work in a wrist non-neutral posture. It is a significant finding because wrist posture has been a poorly characterized risk factor for CTS among workers. Specifically, our study found evidence of increased risk of CTS among workers who perform tasks that require high-force pinch while the wrist is extended. Thus, wrist injury prevention strategies should recommend that workers avoid the combinations of wrist extension and high-force pinching. By that strategy, work-related upper extremity injury may be prevented.

5. 2.1. Recommendations for injury prevention policies

No country currently has occupational injury prevention policies that provide guidelines or standards to prevent wrist injuries. The only available guideline is for shoulder injury prevention. (EU OSHA 2007)

In general, the U.S. and European Union occupational safety and health policies recommend workers avoid working in a non-neutral wrist posture for prolonged periods. However, the guidelines do not provide specific recommendations for upper extremity joints except for the neck and shoulder (Table 1). Likewise, the rules were inadequate for specifically preventing wrist injury. Korea accepted the U.S. guidelines in 2003.

Table 13 Work-related upper extremity musculoskeletal injury prevention guidelines and regulations of US. and Korea (Keyserling et al 1993, Korea (Occupational Safety and Health) OSH Acts 2003).

U.S. OSHA guidelines (Caution zone task or Hazard zone task)	>2Hrs hand above head >2Hrs elbow above shoulder >4Hrs hand above head >4Hrs elbow above shoulder
Korea: 2003 OSH act	>2Hrs hand above head >2Hrs elbow above shoulder >2Hrs elbow behind than torso ≧45° degree of upper arm adduction

Another problem is that interventions to improve wrist posture are not as well established as interventions to reduce worker exposure to other biomechanical risk factors such as force or repetition.

Considering the findings of our study and other similar studies, the postural risk factors should be included for effective prevention. Sadly enough, some strategies recommend stretching exercises to strengthen the upper extremity for injury prevention (Naval special warfare center, n.d.). However, stretching exercises have not been demonstrated to be effective.

Even among the Scandinavian countries (considered leaders on ergonomic strategies), there are no specific recommendations on posture-related interventions to prevent injuries among industrial workers. Most health and safety legislation originates from EU Directives and are adopted by EU countries. Two pieces of regulation relate to posture and upper limb disorders. One is the ‘Manual Handling Operations Regulations’ and the other is the ‘Display Screen Equipment Regulations’.

Additionally, the ILO Ergonomic checklist recommends several upper extremity injury prevention strategies in their machine safety chapter. However, this regulation fails to propose specific criteria to prevent wrist injuries. Policies for injury prevention should include reducing wrist extension with high-force pinch.

5.2.2. Recommendation for a cost-effective prevention: Alternative tool design

An important aspect of addressing posture and force risk factors rather than repetition is that interventions can generally be accomplished with workstation and tool design changes. Interventions for reducing repetition may be costly and reduce productivity.

Multiple studies have demonstrated a positive effect of reducing non-neutral wrist posture by tool and/or work-station design changes (Schoenmarklin 1998; May and Schwoerer 1994; Lincoln et al 2000; Amell et al 2001). A split keyboard that changes wrist posture to neutral can reduce pain severity (Tittiranonda, Rempel, Armstrong, & Burastero, 2000). Conlon reported reduced hazard among engineers when they used an ergonomically designed computer mouse (Conlon, Krause, & Rempel, 2008).

5. 3. Future Research Directions

Based on the study findings, some recommendations are made for future research projects.

Chapter 3 demonstrated methods to improve wrist posture measurement from video at the individual worker level. In the future, it would be useful to conduct video analysis and test reliability using different sampling durations and frequency; increase the number of cameras; and check with electro-goniometer measurements. Electro-goniometer measurements would be considered the gold standard.

In addition, the proposed video-based posture measurement methods could be applied to other upper extremity joints. For example, the method could be applied to measure wrist ulnar/radial deviation, forearm pronation/supination, or shoulder posture.

Another recommendation is to expand the study population to office workers. More and more work is done on computers. However, computer work risks differ from those of manufacturing work and should include contact stress and static loading due to prolonged non-neutral postures.

A final recommendation is to video record tasks for a longer duration than 10 minutes and to record on more than one day. This has been recommended to reduce bias and imprecision (Mathiassen, Wahlström, & Forsman, 2012). It would be useful to determine to what extent video length and frequency influence bias by task type.

5. 4. Concluding remarks

Occupational musculoskeletal disorders are a large burden to society and account for 1/3 of workers' compensation costs. According to the International Labour Organization report (ILO), approximately 270 million workers suffer from non-fatal injuries and another 160 million are injured or ill for prolonged periods from work-related causes. The total cost of treatment, rehabilitation, back-up for vacancy of work-leave, and training new employees is almost 4% of world's GDP. Furthermore, these injuries have a large impact on people during their most productive years (ILO, 2003).

The study findings provide some guidance for preventing CTS, one of the most disabling and costly musculoskeletal disorders. The findings are likely to apply to other upper extremity disorders such as wrist tendonitis or epicondylitis. The findings should be useful to employers, employees, industrial engineers and health and safety specialists. By expanding our knowledge of biomechanical risk factors, we can improve CTS prevention strategies and help workers stay healthy and productive.

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