FINAL PERFORMANCE REPORT:

Musculoskeletal disorders among manufacturing worker

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LIST OF ABBREVIATIONS

ACGIH	American Conference of Government Industrial Hygienists
APL	Abductor pollicis longus
BLS	Bureau of Labor Statistics
BMI	Body mass index
CEVA	Clustered exposure variation analysis
CI	Confidence interval
cm	Centimeter
CTS	Carpal tunnel syndrome
ECU	Extensor carpi ulnaris
EDC	Extensor digitorum communis
EDM	Extensor digiti minimi
EIP	Extensor indicis proprius
EMG	Electromyography
EPB	Extensor pollicis brevis
EPL	Extensor pollicis longus
EVA	Exposure variation analysis
HAL	Hand activity level
HR	Hazard ratio
ILO	International Labour Organization
IOM	Institute of Medicine
JCQ	Job content questionnaire
MSO	Musculoskeletal disorder
MVTA	Multimedia Video Task Analysis
N	Number
NIOSH	National Institute for Occupational Safety and Health
NRC	National Research Council
OSHA	Occupational Safety and Health Administration
OWAS	Ovako Working Posture Analysing System
p	Probability
PANAS-X	Positive and negative affectivity scale
PC	Personal computer
RMS	Root mean square
RULA	Rapid upper limb assessment
RVE	Relative voluntary exertion
SAS	Statistical analysis system
SD	Standard deviation
TWA	Time weighted average
UEMSD	Upper extremity musculoskeletal disorder
VAS	Visual analog scale

ABSTRACT

Introduction. Musculoskeletal disorders (MSD) continue to be important occupational health problems in industry. In order to assess risk factors for upper extremity MSD, we investigated the relationship between occupational exposure to hand-intensive work among 386 household appliance manufacturing workers and (a) upper extremity musculoskeletal symptoms and (b) upper extremity musculoskeletal disorders in a prospective epidemiologic study.

Methods Participants were recruited from one large home appliance manufacturing facility. Exposure to physical risk factors was ascertained with video analysis and EMG. Time in specific tasks and selected administrative/organizational factors were ascertained with a daily task diary. Demographic factors and exposures to occupational psychosocial stressors were ascertained with validated questionnaires. Health outcomes were obtained with a weekly symptom questionnaire and a physical examination conducted by an occupational medicine physician. Descriptive statistics included prevalence and incidence of musculoskeletal symptoms and disorders. Cox proportional hazard methods were used to estimate risk while controlling for confounding. Analyses were conducted separately for hand-arm symptoms, neck-shoulder symptoms, hand-arm disorders, and neck-shoulder disorders.

Results The prevalence of hand-arm symptoms was 19% and the prevalence of hand-arm disorders was 11.8% (Table 5). The most prevalent hand-arm disorder was carpal tunnel syndrome (prevalence=6.8%). The incidence of hand-arm symptoms was 58/100 person years and the incidence of hand-arm disorders was 19/100 person years. The prevalence of neck/shoulder symptoms was 16.8% and the prevalence of neck/shoulder disorders was 7.6%. The incidence of neck/shoulder symptoms was 54/100 person years and the incidence of neck/shoulder disorders was 14/100 person years.

In multivariate analyses, few physical risk factors were associated with MSD outcomes. A non-statistically significant increase of 19% per unit of HAL was observed for hand-arm disorders but not for hand-arm symptoms. Associations between psychosocial risk factors and hand-arm symptoms and hand-arm disorders were relatively large and in the hypothesized direction. Weekly job stress level was statistically significantly associated with all four musculoskeletal outcomes. Job change was statistically significantly associated with hand-arm symptoms and hand-arm disorders.

Conclusion The results of this study support a large role for psychosocial and organizational factors in the development of musculoskeletal symptoms and disorders. Methodological issues, including a highly selected study sample (average job tenure was 16 years) and a high degree of job rotation may have resulted in underestimates of associations between musculoskeletal outcomes and exposure to physical risk factors.

SIGNIFICANT FINDINGS

The prevalence of hand-arm symptoms was 19%

The prevalence of hand-arm disorders was 11.8%

The most prevalent hand-arm disorder was carpal tunnel syndrome (prevalence=6.8%)

The incidence of hand-arm symptoms was 58/100 person years

The incidence of hand-arm disorders was 19/100 person years

The highest rate of incident hand-arm disorders was observed for carpal tunnel syndrome (8.8/100 person-years)

The prevalence of neck/shoulder symptoms was 16.8%

The prevalence of neck/shoulder disorders was 7.6%

The most prevalent neck/shoulder disorder was somatic pain syndrome (also called *tension neck syndrome,* prevalence=5.7%)

The incidence of neck/shoulder symptoms was 54/100 person years

The incidence of neck/shoulder disorders was 14/100 person years

In multivariate models, the association between Hand Activity Level (HAL) score and incident hand-arm disorders was elevated but not statistically significant (HR=1.19, 95% CI=0.90-1.58)

Statistically significantly elevated hazard ratios were observed for all categories of job strain quadrant and hand-arm symptoms and hand-arm disorders when compared to the referent category

Strong and statistically significant effects of weekly stress level and weekly job change were observed for both hand-arm symptoms and hand-arm disorders after adjustment for confounding factors

After adjustment for confounding factors, no statistically significant elevations in risk were observed between any of the physical risk factors and either neck-shoulder symptoms or neck-shoulder disorders

The association between the "low demand, low control" job strain quadrant category and hand-arm disorders was statistically significant (HR=5.61, 95% CI=1.24-25.3)

Self reported job stress, collected weekly on a 0-10 VAS, was strongly associated with both neck-shoulder symptoms (HR=1.36, $p<0.001$) and neck-shoulder disorders (HR=1.31, $p<0.001$)

Self-reported job change, also collected weekly, was strongly associated with both neck shoulder symptoms (HR=3.49, $p<0.001$) and neck shoulder disorders (HR=1.96, $p=0.12$)

TRANSLATION OF FINDINGS

The prevalence and incidence rate of carpal tunnel syndrome among manufacturing workers is greater than rates reported for non-manufacturing workers. This suggests that additional prevention efforts are needed among these workers.

Hand activity may be a risk factor for hand and arm symptoms and disorders. Efforts to control exposure to high levels of hand activity may result in lower rates of musculoskeletal symptoms and disorders.

Occupational psychosocial stress appears to be important contributors to incident musculoskeletal symptoms and disorders. Efforts to control these stressors may result in lower rates of musculoskeletal symptoms and disorders.

Frequent job change appears to be an important contributor to incident musculoskeletal symptoms and disorders, Minimizing the rate of job change may result in lower rates of m musculoskeletal symptoms and disorders.

SCIENTIFIC REPORT

1. BACKGROUND

INTRODUCTION

Musculoskeletal disorders (MSD) of the upper extremities affect tendons, tendon sheaths, muscles, nerves, bursae, and blood vessels of the hands, arms, shoulders, and neck. Examples of specific upper-extremity musculoskeletal disorders frequently reported to be work-related include carpal tunnel syndrome, tendonitis of the hand and wrist, epicondylitis, and certain shoulder and neck disorders [Bernard, 97; National Research Council and Institute of Medicine, 2001; Mani and Gerr, 2000]. The incidence of work-related upper extremity musculoskeletal disorders reported in the United States appears to have increased dramatically during the past twenty years. In 2006, all MSD accounted for 30% of all illness and injury cases involving days away from work in the US (Bureau of Labor Statistics, 2007).

The toll of these disorders in terms of human suffering as well as their economic consequences is enormous. A recent report published by the American Academy of Orthopedic Surgeons estimated the cost of all domestic musculoskeletal disorders (work- and non-work-related) in 1995 at $215 billion [National Research Council — institute of Medicine p 57]. Work-related disorders of the hand account for more lost work days than any other occupational injury [Blair, 1991]. Estimates of the cost of work-related musculoskeletal disorders to the United States economy range from $13 billion to $54 billion in lost wages, medical expenses, and insurance administration costs [Bernard, 1997; Blair, 1991; National Research Council and Institute of Medicine, 2001]. Because of the magnitude of this problem, the Occupational Safety and Health Administration (OSHA) has targeted work-related musculoskeletal disorders as a priority area and has been active in efforts to establish regulations governing exposure to hazards that increase their risk. In addition, the National Institute for Occupational Safety and Health (NIOSH), has included musculoskeletal disorders among those targeted in its National Occupational Research Agenda.

Although some authors continue to express skepticism about the contribution of workplace factors to the risk of musculoskeletal disorders [Vender et al., 1995; Hadler, 1997], many experts find the literature highly suggestive of a relationship between them [Punnett, 2000; Sluiter, 2001, Viikari-Juntura, 1998]. In the following sections, we will review the epidemiologic evidence 1) relating specific ergonomic exposures found in the work environment to upper-extremity musculoskeletal disorders and 2) relating specific musculoskeletal disorders to the occupational environment. While an important body of evidence suggesting an association between physical factors and MSD has also resulted from biomechanical investigations, the current review will focus on epidemiological evidence. This is because the proposed investigation is an epidemiological study.

Of particular relevance to our review of the literature are limitations in the existing literature that make quantitative assessment of risk of MSD associated with specific magnitudes or levels of exposure difficult or impossible. These limitations include imprecise measurement of exposure, lack of examination-based assessment of MSD,

study designs that do not permit assessment of temporal sequence of exposure and outcome, and inadequate control of confounding variables.

EPIDEMIOLOGICAL EVIDENCE: WORKPLACE FACTORS AND MUSCULOSKELETAL DISORDERS

The relationship between specific workplace factors and musculoskeletal disorders has been the subject of two comprehensive reviews in the past several years. In 1997, the National Institute for Occupational Safety and Health published a major review the purpose of which was to "examine the epidemiologic evidence of the relationship between selected MSDs of the upper extremity... and exposure to physical factors at work." [Bernard, 1997] The authors noted that they gave specific attention to " analyzing the weight of the evidence for the strength of the association between [musculoskeletal] disorders and work factors.". In 2001, the National Research Council and the Institute of Medicine published a review "of the scientific literature on the relationship of work and the workplace to musculoskeletal disorders of the low back and upper extremities" [National Research Council and Institute of Medicine, 2001]. The results of these reviews are particularly relevant because both used *a priori* criteria for selection of articles of acceptable scientific quality and both made intensive efforts to identify all potentially relevant articles for consideration. Because of the comprehensiveness of their approach and their influence on investigators in the field, the results of these reviews will be discussed briefly below.

National Institute for Occupational Safety and Health Review

After an initial broad search of the literature, studies were selected for "more detailed review" if 1) exposed and referent populations were well defined, 2), health outcomes were measured by well defined explicit criteria, 3) exposure assessment permitted some inference about repetition, force, extreme joint position, static loading, vibration, and lifting, and 4) study design included population-based, case-control, cross sectional, longitudinal, and case series study designs. Those studies meeting the initial four screening criteria were subject to an additional four evaluation criteria: 1) participation rate greater than 70%, 2) health outcome defined by symptoms and physical signs, 3) exposure and health assessed by blinded investigators, and 4) characterization of specific exposure type (i.e., repetition) and use of exposure assessment instrument for specific exposures. Finally, NIOSH investigators considered the body of evidence using established guidelines or determination of causality.

Neck and Neck/Shoulder Disorders NIOSH authors identified 46 epidemiological studies of neck MSDs and 23 epidemiological studies of neck/shoulder MSDs. Thirty eight of the studies (83%) were cross-sectional in design. When examined by risk factor (repetition, force, posture, and vibration), only four studies were identified that met all four of the additional evaluation criteria. On review of all of the identified studies, the authors concluded that "reasonable evidence" could be inferred for a "causal" relationship between 1) "repetitive work" and neck or neck/shoulder MSD and 2) " forceful exertions" and neck MSD. They also concluded that "strong evidence" could be inferred for an association between high levels of static contraction, prolonged static loads, or extreme working postures and neck disorders. The authors noted that "no

studies reviewed showed a clear dose-response relationship between repetition and neck and neck/shoulder MSDs". They cited only one study in which multiple interventions resulted in a decrease in neck/shoulder MSD as evidence of an exposure response relationship for force and neck/shoulder MSD. They stated in summary that " cumulative exposure-response data is lacking" for the relationship between exposure to workplace physical hazards and neck or neck/shoulder disorders.

Shoulder Disorders The authors reviewed over 20 epidemiological studies of the relationship between workplace factors and shoulder MSD. As was observed for neck and neck/shoulder disorders, only a small proportion of identified studies met all four evaluation criteria used to identify methodologically superior studies. NIOSH authors concluded that none of the studies allowed for a estimation of a quantitative exposure-disorder relationship. Of relevance was the observation that three studies reported significant associations between shoulder flexion or abduction of greater than 60 degrees and shoulder disorders. Two prospective studies showed that the percent of the work cycle spent with the arms elevated or abducted was associated with risk of more severe neck and shoulder disorders. NIOSH authors concluded that "evidence" existed for a "positive association" between 1) "highly repetitive work" and shoulder MSD and 2) "repeated or sustained shoulder postures with greater than 60 degrees of flexion or abduction" and shoulder MSDs. They also concluded that "insufficient evidence" was available for an association between force and shoulder MSDs.

Elbow Disorders (epicondylitis) The authors reviewed 23 epidemiological studies of the relationship between workplace factors and elbow disorders. The only elbow disorder actually addressed by the authors was epicondylitis. Three studies met all four of the evaluation criteria used to identify methodologically superior studies. The authors concluded that evidence was insufficient to support a relationship between repetitive work and epicondylitis. They did find a relationship between forceful work and epicondylitis, however. Again, the authors commented on the difficulty of estimating a quantitative exposure-disorder relationship for epicondylitis.

Carpal Tunnel Syndrome The authors reviewed 30 epidemiological studies of the relationship between carpal tunnel syndrome (CTS) and physical workplace factors. Electrophysiological tests to assist in the identification of CTS were performed in 14 of them. Five epidemiological studies examining CTS and repetition met all four criteria for epidemiological quality. They concluded that "evidence" was found of a positive association between highly repetitive work and CTS. Four epidemiological studies examining the relationship between forceful hand/wrist exertion and CTS met all four criteria. The authors noted that "None of the studies reviewed demonstrated that increasing levels of force alone resulted in increased risk for CTS" [Bernard, page Sa-211. They did state that "there is more evidence of a dose-response relationship for CTS with increasing levels of force and repetition combined". Finally, after review of two studies of the association between posture and CTS that meet the four quality criteria, the authors concluded that evidence was insufficient to show an association between awkward postures "alone" and CTS.

Hand/Wrist Tendinitis The authors reviewed eight epidemiological studies of the relationship between physical workplace factors and hand/wrist tendinitis. Two studies examining the association between repetition and hand/wrist tendinitis met the four evaluation criteria. Only one included a quantitative measure of repetition (which was dichotomized into low and high categories) [Armstrong et al., 1987]. One study was identified that met all four evaluation criteria for the relationship between force and hand/wrist tendinitis. A non-significant elevation in risk was observed between force (dichotomized into low and high categories) and tendinitis in that study. Only one study examining the association between posture and hand/wrist tendinitis met all four evaluation criteria. Posture was not assessed as an individual variable in that study but was considered a characteristic of the high risk occupational group (food packers) [Luopajarvi et al., 1979].

National Research Council and Institute of Medicine Review

Similar to the approach taken by NIOSH, the NRC/IOM panel began by identifying a large number of candidate studies (N=265) and retaining only those that met *a priori* criteria for epidemiological adequacy. The databases examined for candidate articles included MEDLINE (US National Library of Medicine), NIOSHTIC (US NIOSH), HSELINE (UK Health and Safety Executive), CISDOC (ILO, Switzerland), Ergoweb (University of Utah), Ergonomics Abstracts, and ArbLine (Sweden National Institute for Working Life). The criteria for retention of articles were: 1) clearly defined exposed and non-exposed (or comparison) populations, 2) participation rate of 70% or more, 3) well defined and replicable assessment of health outcome (by either self-report or objective assessment), 4) well defined exposure measures (by self-report, job-title, or objective assessment), 5) language of publication was English, 6) publication in a peer-reviewed journal, and 6) publication in the past 20 years. Of the 265 articles initially identified, 13 met the six criteria and included "direct" measures of exposure and another 29 met the six criteria and provided "indirect" measures of exposure. Of the 13 meeting the six criteria and including "direct" exposure assessment, seven were primarily of vibration exposed workers with no direct assessment of exposure to force, repetitive exertions, or awkward postures. Of the remaining six, only four were of "industrial" or "factory" workers [Silverstein et al. 1986; Silverstein et al. 1987; Latko et al, 1999, Ohlsson et al, 1995]. The National Research Council and Institute of Medicine panel concluded that " The findings from the studies reviewed indicate that repetition, force, and vibration are particularly important work-related factors associated with the occurrence of symptoms and disorders in the upper extremities." The panel also noted that "Most epidemiological studies have been summarized as having exposure... measures dichotomized. The ability to make inferences about dose-response relationships is limited in this context."

Summary of the Epidemiological Evidence

For the sake of efficiency, rather than undertaking, *de novo,* a comprehensive review of the epidemiological literature examining associations between occupational exposure to physical factors and UEMSDs, two recent major reviews of the literature have been examined and summarized, Despite differences in detail and scope, the conclusions between them are quite similar, overall. Both reviews identified the physical factors of

repetition and force as important risk factors for the development of UEMSD. (Both also identified hand-arm vibration as an import hazard. However, because the proposed study is not of a vibration exposed cohort, this factor will not be considered further, except as a potential confounding exposure). In addition, both reviews noted that a strong interaction between force and repetition was observed in several studies. Finally, it should be noted that in both reviews, when specific epidemiological quality criteria were applied to the large body of literature examining associations between physical occupational factors and UEMSDs, a large proportion of the studies were excluded.

UPPER EXTREMITY MUSCULOSKELETAL DISORDERS AMONG MANUFACTURING WORKERS

According to the data from the US Bureau of Labor Statistics, manufacturing workers experience a disproportionate number of "repeated trauma" disorders when compared to all other private industry. Specifically, although manufacturing workers comprise only 15% of the entire private workforce, they experienced 68% of all repeated trauma cases [BLS December 2001]. Despite this over-representation of manufacturing among repeated trauma cases, manufacturing sector employees have not been the focus of most epidemiological studies of the association between occupational factors and UEMSDs. In this section, the four published epidemiological studies of manufacturing workers that met either the four NIOSH criteria or the NAS/10M criteria for methodological quality are reviewed.

Silverstein et al. (Silverstein et al., 86; Silverstein et al., 871 performed a cross-sectional study of the associations between force and repetition category and the prevalence of hand-wrist MSDs among manufacturing workers. Force exposure category was estimated for study jobs with forearm flexor surface EMG. A sample of participants employed in each job was measured and the force category (low-force vs. high force) was estimated. The repetition exposure category was estimated for study jobs on the basis of video analysis. Similar to the procedure for force, a sample of study participants was videotaped and the repetition category (low repetition vs. high repetition) was estimated on the basis of a priori defined cycle time and proportion of cycle time spent performing the same type of fundamental cycle. While controlling for potentially confounding variables, analyses were performed to examine the associations between a four-category combined force-repetition exposure variable and selected musculoskeletal health outcomes. The authors observed that high force and high repetitiveness were generally positively associated with hand-wrist musculoskeletal disorders [Silverstein et al., 86]. The combination of high force and high repetitiveness was especially strongly associated with prevalent hand-wrist musculoskeleta l disorders. Similar positive associations were observed between repetitiveness and force and prevalent CTS [Silverstein et al., 87].

Latko et al [1999] performed a cross-sectional study of the association between repetitive work and upper limb tendon disorders, carpal tunnel syndrome, and upper limb discomfort among 352 industrial workers. Jobs were selected to assure adequate variance of repetition. Repetition (and other ergonomic exposures) were rated on a ten

point scale (the Hand Activity Level) [Latko et al., 1997] by independent observers after viewing videotape of study participant performing a job or task. After controlling for potentially confounding factors, statistically significant associations were observed between category of repetition and upper limb discomfort, tendinitis, and hand diagram consistent with carpal tunnel syndrome.

Ohlsson et al. [1995] performed a cross sectional study of the association between repetitive industrial work and UEMSDs among 82 industrial workers exposed to repetitive work tasks and 64 referents without exposure to repetitive work tasks. In addition to exposure assessment by job title, video analysis of postures assumed and the frequency of posture changes was performed. All study participants were administered a standard clinical assessment for objective assessment of musculoskeletal disorders. The prevalence of neck/shoulder diagnoses and the prevalence of elbow/hand diagnoses were significantly greater among the participants performing repetitive work tasks than among the referent subjects. Furthermore, in an analysis restricted to the industrial workers exposed to repetitive work tasks who had detailed posture assessment with video analysis, significant associations were observed between time spent with neck flexion >15 degrees and neck/shoulder diagnoses and time spent with the upper arm abducted >60 degrees and neck/shoulder diagnoses

EXPOSURE ASSESSMENT METHODS IN OBSERVATIONAL EPIDEMIOLOGICAL STUDIES

Exposure assessment methods have been categorized as subjective, observational, and direct measurement [Winkel and Mathiassen, 1994; Burdorf and van der Beek, 1999]. Subjective methods rely on self-report and include questionnaires, structured interviews, or work diaries. Subjective methods are inexpensive to administer but are limited by a number of measurement problems including non-systematic error (imprecision) and systematic error (e.g., bias introduced by differential recall) [van der Beek et al., 1994; Kilbom, 1994; Burdorf and van der Beek, 1999; Spielholz et al., 2001; Hansson et al., 2001]. Consequently, many studies have found that the results from subjective measurements agree poorly with observational methods or direct measurements [van der Beek et al., 1994; Viikari-Juntura et al., 1996; Hansson et al., 2001; Ketola et al., 2001; Spielholz et al., 2001].

Observational methods are a compromise between the simplicity and ease of use (but limited validity) of subjective methods, and the precision and accuracy (but cost and complexity) of direct quantitative exposure measurement [Kilbom, 1994]. Observational methods allow for simple, non-invasive, and efficient exposure assessment of cyclic manufacturing processes [Armstrong et al., 1982]. Examples of observational methods frequently used to assess ergonomic exposures include the " hand activity level" (HAL) [Latko et al., 1997], the "rapid upper limb assessment" (RULA) [McAtamney and Corlett, 1993], and the "Ovako Working Posture Analysing System" (OWAS) [Karhu, 1977].

Direct measures of exposure are more precise than observational methods and are not affected by inter or intraobserver variability [Kilbom, 1994; Juul-Kristensen et al., 1997; Burdorf and van der Beek, 1999]. Examples of direct exposure assessment include

electromyography (EMG) and electrogoniometry. Problems with direct measures of exposure include the cost and complexity of apparatus needed, and the large amount of raw data obtained that must be reduced into a smaller number of metrics that can be used for assessment of exposure-effect relationships. Although a number of data reduction methods have been described [Veiersted et al., 1990; Mathiassen and Winkel, 1991; Hagg et al., 97; Anton, 2002],no consensus has emerged regarding the metrics that are most clearly associated with risk.

Forceful Exertions

Self-assessment of muscular load level has been observed to have low reliability [Wiktorin et al., 1993; Harber et al., 1994; Ketola et al., 2001; Spielholz et al., 2001]. Consequently, subjective methods of assessing exposure to forceful exertions are of little value in epidemiological studies. Additionally, observation methods do not produce a quantifiable value of forceful exertion that can be compared across studies [Viikari-Juntura et al., 1996; Ketola et al., 2001]. Alternatively, direct exposure assessment, such as surface EMG, is a more precise methods of assessing muscle load (van der Beek and Frings-Dresen, 1998; Burdorf and van der Beek, 1999], and has been used in a number of occupational epidemiological studies as a measure of applied force [Bjelle et al, 1981; Silverstein et al., 1987; Malchaire et al., 1997]. The amplitude of EMG (also called "intensity") can be considered a parameter of exertion by itself [Malchaire et al., 1997], because the amplitude of the EMG signal increases with increasing motor effort (Duque et al., 1995; Cook et al., 1998]. The amplitude or intensity of EMG, normalized to a maximal contraction (%MVE) or reference contraction (%RVE), is most often reported [Bjelle et al., 1981; Westgaard et al., 1988; Anton et al., 2001], although several other data reduction methods and summary metrics are available.

Repetition

Subjective assessment of repetition has been observed repeatedly to be of limited utility as an exposure metric in occupational epidemiological studies [Burdorf, 1995; Viikari-Juntura et al., 1996; Ketola et al., 2001; Spielholz et al., 2001]. Although direct measurement of repetition with electrogoniometers provide the most precise estimate [Radwin and Lin, 1993], the use of direct techniques for this purpose is time consuming [Yen and Radwin, 2002] and limits the utility of this technology for use in large epidemiological studies. Observation techniques have been developed which reliably evaluate repetition in cyclic manufacturing processes [McAtamney and Corlett, 1993; Latko et al., 1997; Latko et al., 1999]. Observation methods such as RULA [McAtamney and Corlett, 1993] have been used to evaluate hand-wrist repetition and posture [Roquelaure et al., 1997], but these techniques are more suitable for evaluation of sedentary work [Li and Buckle, 1999]. Latko et al, [1997] developed the HAL scale for rating repetition levels in cyclic work processes. This method uses a 10 point visual analogue scale to simultaneously rate the hand movement speed (hand "busyness"), as well as the duration and frequency of pauses during a work cycle. The HAL is used to determine threshold limit values (TLV) of repetition by the American Conference of Governmental Industrial Hygienists (ACGIH) [ACGIH, 2002]. This method is relatively easy to use and has been shown to have good test-retest reliability [Latko et al., 1997].

However, at this time, the HAL has been used in few field-based epidemiological studies of UEMSDs [Werner et al., 1998; Latko et al., 1999].

Posture

Investigation of self-assessment of posture has shown existing methods to be insufficiently precise for use in epidemiological investigations [Viikari-Juntura et al., 1996; van der Beek et al., 1994; Hansson et al., 2001]. The literature suggests that direct measurement with electrogoniometers or video-based observation is required for assessment of posture during performance of dynamic tasks [Kilbom, 1994; van der Beek and Frings-Dresen, 1998]. Although direct measurements of posture provide estimates that are more precise than that obtained by observation, direct measurement of every participant in a large epidemiological study of manufacturing workers would be impractical because of the lengthy preparation time [Yen and Radwin, 2002]. Observation methods for wrist posture are more difficult to perform, but have been found to have acceptable reliability [McAtamney and Corlett, 1993] and also provide an estimate of the duration of posture [Spielholz et al., 2001]. Furthermore, results from observation of wrist posture has been found to comparable to direct measurement when the worker has been video taped [Spielholz et al., 2001].

Sampling Strategies

Because direct exposure assessment of every participant in an epidemiological study has not always been feasible, investigators have often used direct measures to assess exposure of a sample of workers performing a particular task and have then assigned the mean value to all persons performing that task [Winkel and Mathiassen, 1994; Burdorf and van der Beek, 1999]. While this approach may be the best possible when resources are insufficient for assessment of the entire study population, some misclassification of individual exposure is inevitable, Such ecological assignment of exposure and the misclassification that results likely leads to an attenuation of the observed exposure-outcome relationship [Rappaport et al., 1993; Kilbom, 1994; van der Beek and Frings-Dresen, 1998; fallentin et al., 20011. An exposure assessment strategy in which the exposure of every study participant is measured either directly or by observation (or by a combinatiop of the methods) will result in more precise exposure estimates and will maximize the power of the study to detect exposure-effect relationships [Winkel and Mathiassen, 1994; Seixas and Sheppard, 1996; Fallentin et al., 2001].

OCCUPATIONAL PSYCHOSOCIAL STRESS AS EXPOSURE MEASURE AND POTENTIAL CONFOUNDER

These factors, also known as occupational stress or perceived stress, have only recently come to be widely regarded as important risk factors for upper extremity musculoskeletal disorders. A number of scales or instruments have been proposed for assessment of occupational psychosocial stress. Indeed, one current methodological problem for investigators who want to assess psychosocial stress is the array of instruments (and underlying models) available for use. The most widely used instrument is the Job Content Questionnaire based on the job decision latitude theory of Karasek [Karasek, 1985]. Another instrument used extensively in research performed

by NIOSH investigators is the Generic Job Stress Questionnaire. The instrument includes measures of 13 job stressors, including workload, responsibility, demands, conflict, and job control [Hurrel and Murphy, 1992]. A comprehensive review by Bongers et al. [2002] noted considerable inconsistency among studies examining the relationship between psychosocial factors and musculoskeletal disease. One possible source of the inconsistency may be the cross-sectional ascertainment of both health effects and stress variables. The possibility that the reporting of stress was affected by UEMSDs among some participants is a real concern. Very few studies have assessed occupational psychosocial stressors and UEMSDs prospectively.

CRITIQUE OF THE LITERATURE

Ascertainment of Exposure

The majority of research relating upper extremity disorders to work has used qualitative descriptions of ergonomic hazard or even simply industry or job title rather than objective measurement of specific exposures. Epidemiological studies that have included objective measures of exposure have often dichotomized the exposure measure rather than using a greater number of exposure categories or a continuous measure, limiting the ability to perform quantitative exposure-effect risk assessment. In addition, the majority of epidemiological studies in which objective measures of exposure were performed have not had the resources needed to perform them on all study participants, making the exposure assessment somewhat ecological in nature. More detailed quantitative exposure measures performed on all study participants will permit more precise exposure-effect modeling.

Ascertainment of Health Outcome

Relatively few large epidemiological studies of manufacturing workers have used objective physical assessment to identify soft tissue disorders of the upper-extremity. Although assessment of symptoms is important, the proportion of symptomatic individuals who actually suffer from an objectively documented musculoskeletal disorder has been shown to vary among worksites [Zeier et al., 1987]. Therefore, symptom prevalence alone may be an unstable indicator of the occurrence of musculoskeletal disorders in a working population. This shortcoming in much of the literature relating upper extremity musculoskeletal problems to occupational exposures has led some authors to suggest that work has only been related epidemiologically to discomfort and not to true musculoskeletal disease [Nadler, 1990]. Objective documentation of musculoskeletal disorders requires physical assessment, and in for detection of nerve compression disorders, nerve conduction measurement.

Study Design

Nearly all studies of upper extremity musculoskeletal disorders among manufacturing workers currently available in the peer-reviewed published literature are cross-sectional in design. This design is subject to several biases, including sample distortion from selective survival and, because exposure and effect are ascertained simultaneously, erroneous inferences about the temporal sequence of observed exposure-effect relationships. Distortion of the study sample by selective survival results in a bias towards the null hypothesis.

Cross-sectional studies also result in poor estimates of past exposure. Either current exposure is assumed to represent past exposure or subject recall must be relied upon, which may vary as a function of health status. Prospective collection of exposure and health status information results in improved quality exposure information.

Control of Confounding

While more recent studies have more carefully assessed and controlled for the effect of potentially confounding factors, this important source of bias was not consistently controlled in much of the earlier literature. Potential confounders include age, gender, past musculoskeletal health status, non-occupational exposure to ergonomic hazards, body mass index, and hormonal status [Cannon et al., 1981; Kelsey, 1982; Stevens et al., 1984; Nathan et al., 1992]. Information about these and other potentially confounding variables can be obtained during data collection and used to control for potential confounding during data analysis. Occupational stress, sometimes also called psychosocial stress, is another potential confounder that has been associated with certain occupational tasks [Sauter et al., 1983; Stellman et al., 1987] as well as with discomfort [Hales et al., 19941 and confirmed musculoskeletal disorders [NIOSH, 1993]. Future studies of work and UEMSDs should use well-established instruments and subsequently adjust for its effect during data analysis.

RESEARCH NEEDS AND SIGNIFICANCE

Additional research aimed at clarifying exposure-effect relationships and interaction between exposure variables, will make important contributions to knowledge. Particularly lacking from the available literature is exposure information that is sufficiently detailed to allow for *quantitative risk assessment* of the relationship between exposure to occupational physical hazards and UEMSD.

Research to determine associations more precisely between hand-intensive manufacturing work and UEMSDs will contribute to our understanding only if measures of both exposure to physical work hazards and adverse health effect (i.e., occurrence of musculoskeletal disorder) are standard, objective, and valid. Studies performed longitudinally will permit identification of incident cases and minimize bias from selective survival and prevent the making of revered cause-effect inferences that often affect cross-sectional studies. In addition, estimates of exposure-response relationships can be made with greater precision in a prospective study because exposure assessment can be performed during the observation period and can be repeated quickly following changes to the workstation or to the study participant's tasks.

The study was designed to overcome the major methodological limitations of the existing literature. Results obtained from this investigation will make important contributions to knowledge of the relationship between physical workplace exposures and UEMSDs

2. SPECIFIC AIMS

We investigated the relationship between occupational exposure to hand-intensive work among 386 household appliance manufacturing workers and (a) upper extremity musculoskeletal symptoms and (b) upper extremity musculoskeletal disorders in a prospective epidemiologic study. For every participant in the study, exposures were characterized by objective measurement of the upper extremity force, repetition, and posture for all tasks performed. In addition, study participants maintained a combination task log and *symptom diary* in which the duration of time spent performing each task was self-recorded.

For each participant, a time series of weekly time weighted average exposure measure values was constructed for each exposure metric by combining information from the objective exposure measures and the daily task logs. Additional exposure measurements were performed on each new or modified job task that he/she performs during the study period. The additional exposure measurements allow for changes in exposure intensity to be quantified over time. The task log and symptom diary completed by study participants was also used to capture incident cases of upper extremity symptoms. Participants meeting criteria for self-reported symptom case status were offered a detailed clinical interview and a standard upper extremity physical examination by an occupational physician. Potentially important covariates, including occupational psychosocial stress, work history, health history, and others, were collected at the time of enrollment into the study.

The specific aims of this project were:

1. To determine the incidence of self-reported upper extremity musculoskeletal symptoms and objectively verified upper extremity musculoskeletal disorders among household appliance manufacturing workers over a three year period.

2. To estimate among household appliance manufacturing workers the effects of selected exposure variables including forceful exertions of the hand and arm, frequency of repeated stereotypical motions (i.e., repetitiveness), postures assumed while performing work, and occupational psychosocial stressors on self-reported upper extremity musculoskeletal symptoms and objectively verified upper extremity musculoskeletal disorders while controlling for potentially confounding factors.

3. PROCEDURES AND METHODOLOGY

OVERALL DESCRIPTION OF STUDY DESIGN

This was a prospective epidemiologic study of 386 individuals currently employed or newly hired into production jobs at a household appliance manufacturing facility. Enrollment began in April 2004 and data collection continued until March 2007. Specifically, at the time of enrollment, information about current and past musculoskeletal symptoms was obtained and questionnaires documenting demographic, personal health, work history, and occupational psychosocial stress information were administered.

Information about exposure to physical work hazards was obtained by combining information obtained from two sources. First, for every study participant, the force, frequency and postures associated with all major tasks performed at his/her job were quantified by observational or direct methods. Second, all study participants recorded in a pre-printed task log, on a daily basis, the number of hours he/she spent performing each of the specific tasks that were required by his/her job. In addition, the total number of hours worked at the facility was recorded on a daily basis, The demands of each task documented by observational or direct measurement were combined with the individual participant's log of specific tasks performed over time to create a unique time series of exposure information for that participant. Any changes to the participant's tasks were recorded in the log and triggered a repeated exposure assessment of the new or modified tasks.

Study participants who experienced upper extremity symptoms recorded the severity of the symptoms on a visual analog scale printed on the task log and also documented whether analgesic medication (over-the-counter or prescription) were taken to control the symptoms.

Those subjects with new onset of pain or other upper-extremity symptoms that met a *priori* criteria for symptom case status were interviewed and assessed with a standard clinical physical examination by the study physician (FG).

Multivariate analyses that incorporate time-varying independent variables were performed to determine the effect of selected exposure variables on the musculoskeletal outcomes of interest.

STUDY POPULATION

All male and female employees of age 18 years or greater employed in a large refrigerator manufacturing facility in southeastern Iowa were eligible to participate Details of the study sample are provided below in the Results section.

DATA COLLECTION INSTRUMENTS

Questionnaires

Two separate self-administered questionnaires were completed within one week of entry into the study and a log of daily job tasks and musculoskeletal symptoms was collected weekly during follow up.

Questionnaires administered at time of entry into the study

The first of two questionnaires administered at the time of entry into the study was used to collect demographic and personal health information and the second questionnaire was used to collect occupational psychosocial information [Karasek, 1985, Karasek and Theorell, 1990, Watson et al., 1988, Watson and Clark, 1994, Crawford and Henry, 2004]. Both questionnaires were usually completed within one week of enrollment into the study.

Personal Health Questionnaire

The first questionnaire administered at the time of entry into the study was used to obtain information about demographic characteristics (age, race, gender, height, weight, education, household income), personal health (diabetes, hypothyroidism, rheumatoid arthritis and other collagen vascular diseases, pregnancy, and prior upper extremity or spine disorders), prior upper extremity symptoms, and history of injury or trauma to the upper-extremities. Items included in this initial evaluation are listed in Table 1. The subject's current job title, department, and production line was also obtained. Information about past work, both in the facility and elsewhere was collected.

Musculoskeletal symptoms for the week prior to the date of questionnaire administration were assessed with standard questions about symptom quality, severity, and duration. These are the same questions that were used on the combined Daily Task Log and Symptom Diary (see *Daily Task Log,* below). A positive response to the symptoms questionnaire was defined as a report of pain, numbness, tingling, or burning 1) of 30 minutes or more total duration over the course of the previous week, 2) of intensity "5" or higher on a 0-10 visual analog scale or resulting in use of analgesic medication, and 3) not resulting from acute trauma. Newly enrolled subjects who reported the occurrence of such upper-extremity musculoskeletal symptoms were offered a standard clinical assessment of the upper extremities. Details of the standard clinical assessment are described in the *Clinical* Assessment section, below.

Occupational Psychosocial Stress Questionnaire

The second questionnaire administered at the time of entry into the study assessed occupational psychosocial stress. Scales were selected from the Job Content Questionnaire [Karasek, 1985; Karasek and Theorell, 19901 and the Positive and Negative Affectivity Scale [Watson et al., 1988, Watson and Clark, 1994, Crawford and Henry, 2004]. Scales from both instruments have good reliability and validity and both instruments have been used in several large studies of work-related musculoskeletal disorders. Specific psychosocial measures obtained are listed in Table 1.

Questionnaires administered during the follow-up period

Combined Daily Task Log and Symptom Diary

All study participants completed a brief pre-printed log of (1) daily work practices and work organization and (2) symptoms experienced during the preceding seven days. The logs were collected and reviewed weekly. The use of a symptom diary allowed us to

determine accurately when symptoms began, and therefore, to better determine the temporal relationship between exposures of interest and the development of symptoms [Kelsey, 1986]. In addition, the daily recording of hours worked at specific tasks is more accurate than periodic recall and is not susceptible to recall bias.

Work practices and work organization factors included on the Daily Task Log were hours worked each day at each work task, the number and duration of unscheduled breaks, number of days not worked, and any changes to tasks or work or reassignment of job.

The log was pre-printed with a grid on which each column was labeled with a day of the week and each row was labeled with the set of possible tasks consistent with the study participant's job. The time required to record the necessary daily information was approximately one to two minutes. A copy of the task log used is included as Appendix 1.

Incident musculoskeletal symptoms were assessed each week with standard pre-printed questions about symptom severity and duration in the Task Log and Symptom Diary. These are the same questions that appeared on the personal health questionnaire administered at the time of entry (described above), As was described for the personal health questionnaire, responses met the study case definition of musculoskeletal symptoms when pain, numbness, tingling, or burning were 1) of 30 minutes or more total duration over the course of the previous week, 2) of intensity "5" or higher on a 0-10 visual analog scale or resulted in use of over-the-counter or prescription analgesic medication and 3) not the result of acute trauma. Study participants reporting symptoms that meet the study case definition were asked to participate in the clinical assessment (a targeted physical examination performed by an experienced clinician). Details of the standard clinical assessment are described in the Clinical Assessment section, below.

ASSESSMENT OF EXPOSURE TO PHYSICAL FACTORS

Overview of exposure assessment strategy

Each participant's exposure was measured while he/she performed each of his/her tasks. The results obtained from exposure assessment of each task were then combined with a log of hours in which the duration of each task was recorded on a daily basis. This information was used to estimate the TWA exposure for that day and, subsequently, across each week.

For each study participant, a 10 minute sample of the intensity and duration of forceful exertions, frequency and repetition of hand movement, and postures assumed by the upper extremity and neck was made during typical performance of all of the participant's specific tasks (up to a maximum of six tasks). For study participants with multiple tasks, every task was sampled separately so that measures of exposures typical of that study participant for the tasks that he/she performed were obtained. Specific methods (equipment and procedures) are described below.

In order to construct a time series of weekly exposure information for each participant, the amount of time spent in each task was recorded on the pre-printed task log on a daily basis by every study participant. The logs were collected weekly from the participants. Included on the pre-printed log was a question about changes in task or job during the week that might affect relevant physical exposures. Study participants reporting a change in task or job during the follow-up period were assessed by the study ergonomist. If the ergonomist determined that physical exposures associated with the job or task changed in a biomechanically meaningful way from the original assessment then repeated objective exposure measures were obtained. Following repeated measurement, the database of exposure information for that employee was then updated with the new information.

Forceful Exertions

Forceful exertions of the flexor and extensor forearm, as well as the shoulder girdle, were estimated with surface electromyography using standard electrode locations over the forearm flexors, forearm extensors, and upper trapezius muscles [Zipp, 1982]. *The fundamental variable of forceful exertions* was the mean of the task-specific normalized root-mean-square (RMS) EMG amplitude (expressed as percent relative voluntary exertion, %RVE). As described above, a separate mean %RVE value was assigned to each task for each study participant. A weekly mean time weighted average (TWA) of %RVE value was then estimated by weighting the mean %RVE for each task by the proportion of the total workweek the participant spent engaged in each tasks. The weekly mean TWA of %RVE was the forceful exertion metric used in the statistical analysis.

Instrumentation: The surface EMG electrodes (EQ Inc., Chalfont, PA) had dual 8 mm diameter bipolar silver-silver chloride surfaces encased in 33 x 10 mm plastic blocks, an inter-electrode distance of 22 mm, and on-site preamplification with a gain of 35 to substantially minimize or eliminate artifact. Cross-talk between EMG electrodes has been estimated to be < 5% with a maximal muscular contraction [Solomonow, 1994]. The electrodes were attached to a custom 4-channel data logger system consisting of three components: 1) a microprocessor unit (Tattletale Model 8v2, Onset Computer Corp., Pocasset, MA, USA), 2) EMG instrumentation circuitry providing analog RMS processing in real-time using a 100 ms time constant, gain of 1000, bandwidth of 40-4000 Hz, and common-mode rejection of 87 dB at 60 Hz, and 3) a compact flash storage unit (PERCF8V21, Persistor Instruments Inc., Marstons Mills, MA, USA) . The data logger system also provided access to both the unprocessed (i.e., raw) and RMS-processed EMG signals through a 9-pin D-sub connector for monitoring purposes. The RMS-processed EMG signals were sampled at 100 Hz, and the data stream was recorded directly to the compact flash storage unit

The data logger fit easily into a small fanny pack worn by the study participant and did not interfere with work tasks. The EMG signal was synchronized with the videotape recordings made during exposure assessment for quality control purposes (see the *Repetition* section below for procedures). Signal quality of the EMG was monitored before and after recording through a 12 bit analog-to-digital PCMCIA card (PCM-16/330,

Datapac MS-2, RUN Technologies) connected to a laptop personal computer (Sony VAIO GR P3/1.13 GHz).

Procedures, Normalization, and Analysis: At the time of recording, the EMG electrodes were attached to the skin of the study participant, with the leads taped securely to avoid motion artifact, and connected to the data logger system. To minimize employer burden with setup time, the dominant extremity was sampled for all participants. Normalization (calibration) of the flexor and extensor forearm EMG was conducted by having subjects perform three, 15 sec. submaximal (9 kg) isometric reference grip exertions (%RVE) using a calibrated hand dynamometer (GripTrack Commander, J-Tech Medical Industries, Heber City, UT). Normalization of the upper trapezius EMG was conducted by having subjects perform three, 15 sec. submaximal isometric exertions with the shoulder in 90^0 of abduction and slight horizontal adduction, the elbow fully extended and the forearm prorated, and with a 2 kg weight placed across the dorsum of the hand. [Mathiassen et al., 1995]. Subjects were given a one minute rest in between all normalization contractions, with resting EMG recorded and subtracted from all EMG. Subjects then returned to work for approximately 30 minutes while the EMG representation of muscle activity was recorded. All post-recording EMG analyses were performed in the laboratory with custom software written in LabVIEW® version 7.1 (National Instruments, Austin, TX, USA) [Fethke et al., 2004].

Repetition

Repetition of upper extremity exertions was assessed with the Hand Activity Level metric [HAL; Latko et al., 19971. The HAL is an observation-based method using a 10 cm visual analogue scale with verbal anchors for rating of observed hand movements. *The fundamental variable of repetition* was the task-specific HAL rating. As described above, a separate HAL rating was assigned to each task for each study participant. A weekly mean time weighted average (TWA) of the HAL rating was then estimated by weighting the HAL rating for each task by the proportion of the total workweek the participant spent engaged in each tasks. The weekly mean TWA of the HAL was the repetition metric used in the statistical analysis.

Data collection for assessment of repetition was conducted with two digital video cameras (Sony DCR-TRV27, Sony Corporation, Tokyo, Japan) placed on tripods positioned approximately 10 m from the subject. The video cameras were positioned to minimize parallax errors and obstructed views. One camera was focused on the dominant side sagittal plane of the subject (i.e., right or left side, depending on handedness) and the other on either the anterior or posterior frontal plane, depending on work station accessibility.

In the laboratory, investigators experienced with ergonomic analysis rated the repetition level on the HAL scale for each subject and task by viewing three representative work cycles from the video recording. Consensus of the rating was obtained in the manner described by Latko et al [1997]. If a task was composed of two or more distinct subtasks with differing repetition levels, a rating was made for each subtask and a time-weighted average repetition was estimated.

Posture

Postures of the neck, shoulder, and wrist were assessed with a video work-sampling method, MVTA (Madison, Wisconsin), which is similar to PATH [Buchholz et al., 1996; Paquet et al., 2001]. The primary variable *of* posture was the percentage of task time spent in various ranges of motion of the neck, shoulder, and wrist. Neck posture was categorized as "neutral" (20° extension to 45° flexion), "non-neutral flexion" (>45° flexion), or "non-neutral extension" (>20° extension) [Keyserling, 1986; Juul-Kristensen et, al., 1997]. Three shoulder posture categories were used: 0°- 59° flexion/abduction, 60°- 90° flexion/abduction and >90° flexion/abduction [Keyserling, 1986; Juul-Kristensen et. al., 1997]. Since there is no agreement in the literature on the definition of non-neutral wrist posture, and the precision of estimates of observed wrist posture is modest [McAtamney and Corlett, 1993; Moore and Garg, 1995; Juul-Kristensen et al., 2001; Ketola et al., 2001], the duration of work time in only three categories of wrist posture were determined. Those postures were "neutral" (the range from 30° flexion to 30° extension), "non-neurtral wrist flexion" (>30° flexion) and "non-neutral wrist extension" (>30° extension) [Spielholz et al., 2001].

Posture analyses were performed using Multimedia Video Task Analysis (MVTA) software (Ergonomics Analysis and Design Research Consortium, 2003]. The same three representative work cycles identified for the HAL analyses were used for the posture analysis. For each cycle, postures of the neck and upper extremity were categorized on a frame-by-frame basis [Spielholz et al., 2001]. The percentage of time in each posture category was then calculated as the frequency count of observations within each category divided by the total number of video frames across the three work cycles.

Exposure Assessment for Non-Cyclic Tasks

The exposure assessment procedures were slightly adjusted for tasks considered to be non-cyclic. Non-cyclic tasks were defined as 1) tasks for which there was no identifiable standard work cycle (e.g., maintenance activities) or 2) tasks for which the identifiable work cycle exceeded three minutes in duration, For non-cyclic tasks, the exposure assessment duration was increased from 10 minutes to 20 minutes.

For forceful exertion, the task-specific mean RMS EMG amplitude was computed over the 20 minute exposure assessment duration. For repetition, a fixed-interval sampling strategy was used to compute the task-specific HAL ratings. The 20-minute video recording was parsed into 10 two-minute periods, and a HAL rating was made during observation of the first 30 seconds of each two-minute period. The ten HAL ratings were then averaged and rounded to the nearest whole number to arrive at the final HAL rating for the task. For posture, the first 30 seconds of each two-minute period from the 20-minute video recordings were analyzed on a frame-by-frame basis. The percentage of time in each posture category was then calculated as the frequency count of observations within each category divided by the total number of video frames across the ten 30-second analysis periods.

Breaks

All employees received a 9 minute break during first part of their shift, a 30 minute lunch/dinner break, and a 6 minute break in the last part of their shift. Although EMG recording continued, video recordings were suspended during breaks. In addition, the total exposure assessment time did not always span one or more break periods, especially for participants with three or fewer tasks. Therefore, information about the effect of breaks was not available for this investigation.

CLINICAL ASSESSMENT

Symptoms

Study participants reporting symptoms on the initial questionnaire or on the weekly log that met the study symptom case definition were asked to participate in the Clinical Assessment (a targeted physical examination) generally within one week of the symptom report.

Disorders

As indicated above, study participants who experience symptoms who met the study case definition were asked to participate in a Clinical Assessment which included a face to-face interview and a standard targeted upper extremity physical examination. All Clinical Assessments were performed by the principal investigator, a board certified internist and occupational medicine physician.

All upper extremity musculoskeletal examinations were performed in a standard manner consistent with current clinical practice. The examination included inspection, palpation, active and passive range of motion assessment, determination of motor strength, evaluation of cutaneous sensation, and performance of specific provocative maneuvers including Phalen's test, Tinel's sign, Finkelstein's sign, and Yergeson's test. The examination protocol is provided in Appendix 1.

Because no "gold standard" assessment is available for any diagnosis except carpal tunnel syndrome, the criteria selected for use in this epidemiologic study are based on case definitions published over the past 20 years [Waris et al., 1979; NIOSH, 1993, Harrington et al., 1998, Sluiter et al., 2001, Gerr et al. 2002]. The disorders considered possible health outcomes for the proposed investigation are tension neck syndrome, radicular pain syndrome, rotator cuff tendinitis, bicepital tendinitis, medial epicondylitis, lateral epicondylitits, DeQuervain's tendinitis, flexor carpi radialis tendinitis, flexor carpi ulnaris tendinitis, digital extensor tendinitis, digital flexor tendinitis, distal flexor tenosynovitis (trigger finger), and carpal tunnel syndrome. The case definitions of these disorders proposed for use in this investigation are provided in Appendix 1.

SUBJECT RECRUITMENT AND RETENTION

All employees of the study facility were given letters describing the study signed by the plant health and safety manager, the local union president, and the study PI. In preparation for recruitment, a list of jobs was developed by study personnel in collaboration with plant personnel with knowledge of the manufacturing facility. Jobs were then selected randomly from the list and the worker(s) performing that job was

identified. After receiving permission from the line supervisor (i.e., the "team leader") to speak to the worker, he/she was approached by a study staff member and asked if he/she was interested in hearing more about the study described in the letter. If the worker was interested in participating, a time was arranged for answering questions, obtaining written informed consent, and completing study questionnaires. Once consent was obtained, the research assistant administered the initial questionnaires and oriented the participant to the weekly task log. Study participants were informed that they would receive $25 after completion of the entry questionnaires and completion and return of the first four weekly task logs. Additionally, the study participant received $5.00 after each 16 weeks of participation and $25.00 on the anniversary date of their entry into the study for every year they were in the study.

After successful enrollment, the ergonomic assessment team scheduled the newly enrolled study participant for exposure assessment within one week of enrollment.

No subject approached for recruitment into the study was excluded from participation because of co-morbid conditions. Rather, during data analysis, results of study participants with co-morbid conditions (e.g., arthritis) were managed statistically to prevent bias.

DATA MANAGEMENT

Data Collection

Information was collected by the research assistants, the ergonomist, and the examining clinician. All data were collected according to standard protocols. Self-administered questionnaires completed by participants at the time of entry into the study were reviewed for completeness and consistency by the research assistant when she/he picked them up at the study site. Since the logs were collected at the site, they were reviewed for missing values and inconsistencies according to a standard protocol and attempts were made at that time to reconcile as many inconsistencies as feasible with the study participant.

Copies of all paper and magnetic files were kept in locked cabinets at The University of Iowa. All computer-based files required password access.

The primary key for each data collection instrument (or form) was the project assigned study identification number (SIN). All workers who consented to participate in the study were assigned a SIN.

Data Processing

Forms were inspected for research protocol violations and data were edited according to a standard protocol and then entered. The data entry program included range and validity checks. Any errors or inconsistencies identified by the above procedures were reviewed by a committee consisting of the data manager, project director, and principal investigator.

Data Bases

Two related data bases were maintained for the project. These data bases contain (1) data collected from the study participants and (2) tracking information. Each of the two data bases used separate files for each form; there were multiple forms per subject and repeated administration of the same form per subject. Therefore each data collection event was uniquely identified by SIN, type of form and date.

QUALITY CONTROL AND QUALITY ASSURANCE PROCEDURES

The EMG data loggers were evaluated weekly for proper performance by recording a known signal and evaluating the output. The EMG and video recordings were evaluated weekly by a co-investigator to assure that the data were valid. The presence of artifacts (EMG data) or parallax issues (video) were assessed and corrective actions taken, including reassessment of exposure for affected participants, when found.

Because of the large data burden and the need for continual assurance that data collection instruments were returned to study staff, the computer consultant wrote a series of programs designed to produce study status reports providing weekly information on the number of study participants being followed at any given time and the completeness of all data collection instruments for them. Those study participants who had not completed all questionnaires were identified on the status reports and study staff made contact with them to obtain missing information.

PARTICIPANT NOTIFICATION OF STUDY RESULTS

Each study participant was sent a letter that described his/her clinical examination results within four weeks of the examination. If the examination revealed any findings requiring urgent action the participant was notified immediately and the examining clinician was responsible for ensuring that timely management of the condition was initiated.

DATA ANALYSIS AND STATISTICAL METHODS

All analyses were performed using the SAS statistical package [SAS Institute, Carey, NC]

For the purpose of maximizing statistical power for estimates of association, shoulder and neck disorders were pooled in the initial data analysis and hand and wrist disorders were pooled in the initial data analysis. The analyses described below were executed separately for each musculoskeletal outcome of interest, that is, (a) neck or shoulder symptoms, (b) neck or shoulder disorders based on the Clinical Assessment, (c) hand or arm symptoms, (d) hand or arm disorder based on the Clinical Assessment.

Since this was a prospective study, it was possible to calculate instantaneous risks and relative risks using survival analysis methodology [Cox and Oakes, 1984; Kalbfleisch and Prentice, 1980]. Survival time was taken as the time from enrollment to outcome. Consistent with standard analytical practice, those workers who left the study without manifesting the outcome were considered censored at the time they left the study. Instantaneous relative risk is also known as relative hazard. The two terms are used

interchangeably here. Data analytic techniques are provided for each of the primary specific aims below.

Two full sets of data analyses were performed. In one set of analyses, all continuous variables (both, the exposure variables of primary interest as well as the potentially confounding covariates) were categorized and the analysis subsequently performed with dummy variables for each category. In the other set of analyses, all continuous measures were used in their continuous form (i.e., they were not categorized). The advantage of categorizing independent variables is that doing so allows non-linear relationships with the outcome to be observed. The disadvantage is that doing so substantially increases the number of covariates in the multivariate models. Conversely, the advantage of including continuous variables is that the models are less likely to be over parameterized but, associations that are not linear will still be estimated with a linear assumption.

Specific Aim 1

Incidence The incidence rate of each specific clinical outcomes was estimated as the number of workers newly manifesting the outcome of interest divided by the total person-time of exposure. Incidence rates were calculated separately for each of the four primary MS outcomes (i.e., neck/shoulder symptoms, neck/shoulder disorders, hand-arm symptoms, and hand-arm disorders). Incidence rates were also be calculated for all specific conditions meeting study case definitions.

Specific Aim 2

Unadjusted relative risks Unadjusted relative risks of the associations between 1) demographic and personal health factors, 2) estimates of psychosocial and work-organizational factors and 2) measures of physical work exposures and each of the four incident musculoskeletal outcomes were estimated separately using extended Cox proportional hazards models [Cox and Oakes, 1984]. The association between each independent variable and each of the musculoskeletal outcomes was tested for statistical significance with the log rank test. Those workers who left the study without experiencing an event contributed person time from entry to withdrawal and were censored at the time of withdrawal.

Initial screening of potential confounding variables. Because of the large number of potential confounding variables, an initial screening to eliminate variables that were unlikely to be confounders was performed. Those variables that were not associated with survival to each outcome in the unadjusted analyses described above were unlikely to be confounders. Specifically, the association of covariates with survival to each of the four outcomes was estimated with Cox proportional hazards models. Any variable associated with survival to the outcome with probability of <0.2 was retained as a potential confounder and included in the multivariate models for that outcome (described below).

Multivariate analysis, Relative risks (i.e., hazard ratios) of the association between selected exposure variables and musculoskeletal outcomes were estimated using

extended Cox's proportional hazards model with time to the outcome as the dependent variable. Separate models were fit for each of the four musculoskeletal outcomes. Time-dependent covariates were used to model a change in a subject's risk due to changes in her/his exposure during the course of the study [Cox and Oakes, 19841. Individuals whose exposure changed during the course of the study contributed person-time to the first exposure category and, following the change, contributed person-time to the subsequent exposure category [Kleinbaum, 1996].

Exposure to psychosocial/work-organizational factors. For each of the four primary outcomes (i.e., neck/shoulder symptoms, neck/shoulder disorders, hand-arm symptoms, hand-arm disorders), the initial multivariate models included, as independent variables, *a priori* selected psychosocial measures and all potentially confounding variables remaining after the screening procedure described above. For all four outcomes, the *a priori* psychosocial measures were *job strain* (using the "quadrant" category structure of this metric, i.e., "low control, high demand", "low control, low demand", "high control, high demand" and "low control, high demand"), *coworker support, supervisor support* [Karasek, 1985] *and negative affectivity* [Watson, 1988].

Once a full model was constructed, potentially confounding variables were eliminated one at a time starting with the least statistically significant covariate (i.e., the potentially confounding covariate with the highest p-value). With removal of the covariate, changes in the hazard ratios for each of the *a priori* selected psychosocial/work-organizational factors exposure variables were examined. If the hazard ratios for any of the *a priori* ergonomic exposure variables changed by more than 15% when the potentially confounding variable was removed, then it was considered an actual confounding variable and was subsequently retained in the model. The potential confounder with the next weakest association with the outcome was identified and removed from the model and the process of examining changes in hazard ratios repeated. In this sequential manner, all covariates, regardless of the strength of their associations with the outcome, were subject to removal. Each final model included all of the *a priori* selected exposure metrics (which were retained regardless of the strength of their associations with the outcome) and only those covariates determined empirically to confound their associations with the outcomes.

Because of fundamental differences between the psychosocial measures described in the previous paragraph and the two time-varying psychosocial stress/work organizational variables collected weekly on the task log (i.e., weekly stress level reported on a 0-10 VAS and report of a change in job or specific duties), separate multivariate analyses, with screening for confounding as described above, were performed for these two exposure variables.

Exposure to physical risk factors. In a manner analogous to that used for multivariate modeling of the effects of exposure to psychosocial/work-organizational risk factors (described above), for each of the four primary outcomes, the initial multivariate model

included, as independent variables, *a priori* selected physical exposure variables of interest and all potentially confounding variables remaining after the screening procedure described a bove. The *a priori* selected exposure variables were chosen for inclusion in the multivariable models on the basis of biomechanical and physiological reasoning. For example, the EMG measures of the trapezius muscle were used in models of time to neck/shoulder disorders and not in models of time to hand-arm disorders. Alternatively, EMG measures of the forearm extensors were used to model extensor tendon disorders and not neck shoulder disorders. In this manner, the risk of spurious associations was minimized.

As described above, once a full model was constructed, potentially confounding variables were eliminated one at a time and the change in the hazard ratios for the association of each of the ergonomic exposure variables with the musculoskeletal outcome was examined. The least statistically significant potential confounder (i.e., the potential confounder with the largest p-value) was removed first, with the next least statistically significant potential confounder removed next, and so-on. In a manner analogous to that used for the psychosocial/work-organizational factors, if the hazard ratios for any of the *a priori* ergonomic exposure variables changed by more than 15% when the potentially confounding variable was removed then it was considered an actual confounding variable and subsequently retained in the model. All covariates, regardless of the strength of their associations with the outcome, were subject to removal. Each final model included all of the *a priori* selected exposure metrics (which were retained regardless of the strength of their associations with the outcome) and only the covariates empirically determined to confound their relationship with the outcomes.

4. RESULTS

Study Participants

Contact was made with 749 workers of whom 386 agreed to participate and signed an informed consent. Flow charts that depict these study participants for hand-arm symptoms, hand-arm disorders, neck/shoulder symptoms and neck/shoulder disorders are provided in Figures 1 and 2. Approximately ten percent of those who provided informed consent did not complete the follow-up phase of the study. Participation rates varied slightly across the four study outcomes and were about 50% for each. Two hundred eighty two study participants contributed person time to the analyses of incident hand-arm symptoms, 303 study participants contributed person time to the analyses of incident hand-arm disorders, 290 study participants contributed person time to the analyses of neck/shoulder symptoms and 318 study participants contributed person time to the analysis of incident neck/shoulder disorders.

Demographic and personal health characteristics

Demographic and personal health characteristics of the study sample are provided in Table 2 for the 318 study participants who contributed person time to the analysis of incident neck shoulder symptoms (because of substantial overlap of study participants across the four health outcome cohorts, demographic characteristics of the participants included in the other three sets of analyses are nearly identical to those of the neck/shoulder sample and are not presented). The mean age of the study sample was about 43 years and was just over half female. The average BMI was in the range of " overweight" (mean BMI=27.5, SD=5.4), Slightly fewer than one-third of the sample had education beyond high school. About one-third were smokers. Slightly more than one-quarter of the sample worked on second shift. The study participants had an average of 16 years tenure at the study facility.

Psychosocial and work organization characteristics

Means of the decision latitude scale, psychological job demand scale, coworker support scale, and supervisor support scale of the Job Content Questionnaire are reported in Table 3. Although not commonly reported by investigators, these values are similar in magnitude to those reported by the minority of investigators who provide them. In addition, mean negative affectivity and mean positive affectivity scores of the Positive and Negative Affect Schedule, weekly job stress, and proportion of person weeks during which a job change was reported are provided in Table 3.

Physical exposure characteristics

Descriptive statistics for physical exposure measures are provided in Table 4. The mean HAL was similar to that reported by other studies of manufacturing workers (HAL mean=4.7, SD=1.3). Mean percent times in non-neutral postures were relatively low, ranging from 2.4% (SD=4.0) for shoulder flex/abduct >90° to 14.6% (SD=15.2) for neck flexion. Mean percent relative voluntary exertion (%RVE) of the dominant forearm extensor muscles, forearm flexor muscles, and trapezius muscle were 47.2% (SD=27.3), 90.0% (SD=74.5) and 46.1% (SD=44.2).

Prevalence and incidence of musculoskeletal symptoms and disorders

Hand-arm

On entry into the study, the prevalence of hand-arm symptoms was 19% and the prevalence of hand-arm disorders was 11.8% (Table 5). The most prevalent hand-arm disorder was carpal tunnel syndrome (prevalence=6.8%).

The incidence of hand-arm symptoms was 58/100 person years and the incidence of hand-arm disorders was 19/100 person years (Table 5). Among hand-arm disorders, the highest incidence rate was observed for carpal tunnel syndrome (8.8/100 person-years). Common tendon disorders included lateral epicondylitis (6.2/100 person years) and DeQuervain's tendonitis (tendonitis of the first dorsal compartment, 3.1/100 person years).

Neck/shoulder

The prevalence of neck/shoulder symptoms was 16.8% and the prevalence of neck/shoulder disorders was 7.6% (Table 5). The most prevalent neck/shoulder disorder was somatic pain syndrome (also called *tension necksyndrome,* prevalence=5.7%).

The incidence of neck/shoulder symptoms was 54/100 person years and the incidence of neck/shoulder disorders was 14/100 person years (Table 5). Among neck/shoulder disorders, the highest incidence rate was observed for somatic pain syndrome (10.7/100 person years). Incident rotator cuff tendonitis and bicipital tendonitis were also common.

Crude and multivariate associations between demographic, psychosocial, work organization and physical risk factors and musculoskeletal outcomes

Hand-arm outcomes

Demographic factors Unadjusted associations between demographic factors and hand-arm outcomes are presented in Table 6. Statistically significant associations were observed between hand-arm symptoms and female sex (HR=1.84, p=0.003), comorbid conditions (HR=1.77, p=0.02), past history of arm pain (HR=3,04, p<0.001), hours per week at second job (HR=1.05, p=0.003), and hours per week in upper extremity intensive non-work activities (HR=1.04, p=0.009). With the exception of hours per week in upper extremity intensive non-work activities (HR=0.99, p=0.82), associations between hand-arm disorders and the demographic factors were similar in magnitude to those between hand-arm symptoms and the demographic factors.

Psychosocial and work organization *risk factors* No statistically significant unadjusted associations were observed between coworker support, supervisor support, negative affectivity, or positive affectivity and either hand-arm symptoms or hand-arm disorders (Table 7). Large and statistically significant unadjusted associations were observed between most job strain quadrants when compared to the referent job strain quadrant (" high control, low demand"). Consistent with expectation, the largest unadjusted associations were observed for the "low control, high demand" job strain category (HR for hand-arm symptoms = 3.39, p<0.001; HR for hand-arm disorders = 5.48, p<0.001). A strong association was observed between the continuous strain ratio value and both,

hand-arm symptoms and hand-arm disorders. The large magnitude of these hazard ratios may mislead some readers since the full range of values for this variable among members of the study sample was less than unity and the hazard ratio is a metric of risk per unit change of the independent variable (the continuous strain ratio, in this case). Self reported job stress, collected weekly on a 0-10 VAS, was strongly associated with both hand-arm symptoms (HR=1.39, p<0.001) and hand-arm disorders (HR=1.31, p<0.001). Note that the HR is per unit increase of weekly job stress. Finally, self-reported job change, also collected weekly, was strongly associated with both hand-arm symptoms (HR=4.03, p<0.001) and hand-arm disorders (HR=3,29, p<0.001).

Physical risk factors No statistically significant unadjusted associations were observed between the five physical risk factors and either hand-arm symptoms or hand-arm disorders (Table 8). The only suggestion of an effect was for the association between the HAL score and hand-arm disorders (HR=1.2, p=0.12). Note that the reported hazard ratio is per unit increase of HAL score which has permissible values between zero and ten.

Multivariate models Final multivariate models of associations between hand-arm outcomes and physical and psychosocial risk factors are presented in Table 9. In addition to the exposure variables listed in the table, confounding variables that were also included in each model are provided as notes to the table. After adjustment for confounding factors, no statistically significant associations were observed between any of the physical risk factors and either hand-arm symptoms or hand-arm disorders. In multivariate models, the association between HAL score and incident hand-arm disorders remained elevated but was not statistically significant (HR=1.19, 95%CI=0.90-1.58).

Consistent with the unadjusted analyses, elevated hazard ratios were observed for all categories of job strain quadrant and hand-arm symptoms and hand-arm disorders when compared to the referent category. The effect was strongest for hand-arm disorders. Specifically, both "high demand-high control" and "high demand-low control" categories had a five-fold increase in risk when compared to the referent category (H Rhi$_1$h $_{\text{demand, high control}}$ = 4.99, 95% CI = 1.33-18.7; H $R_{h,gh\ \text{demand, mw control}}$ = 4.94, 95% CI = 1.31-18.7). Because of small cell sizes, however, estimation precision was poor and, consequently, confidence intervals were large for these outcomes. The strong and statistically significant effects of weekly stress level and weekly job change on both hand-arm symptoms and hand-arm disorders persisted after adjustment for confounding factors.

Neck-shoulder outcomes

Demographic factors Unadjusted associations between demographic factors and neck-shoulder outcomes are presented in Table 10. Statistically significant associations were observed between neck-shoulder symptoms and female sex (HR=2.32, p<0.001) and past history of neck-shoulder pain (HR=2.07, p=0.02). Nearly statistically significant associations were observed between neck-shoulder symptoms and education beyond high school (HR=1.48, p=0.07) and history of disc disease (HR=2.61, p=0.06). When

compared to unadjusted association with neck-shoulder symptoms, unadjusted associations between female sex (HR=5.46, p<0.001) and past history of neck-shoulder pain (HR=3.76, p=0.002) and neck-shoulder disorders were considerably larger. Similar to neck-shoulder symptoms, a history of disc disease was strongly, but not statistically significantly, associated with and neck-shoulder disorders (HR=3.21, p=0.11).

Psychosocial and work organization risk factors No statistically significant unadjusted associations were observed between coworker support, supervisor support, or positive affectivity and either neck-shoulder symptoms or neck-shoulder disorders (Table 11). A marginally statistically significant unadjusted association in the expected direction was observed between negative affectivity and neck shoulder symptoms (HR=1.04, p=0.05) but not neck-shoulder disorders (HR=1.03, p=0.30). Unadjusted associations of moderate size and marginal statistical significance (p=0.04-0.15) were observed between the three job strain quadrants and neck-shoulder symptoms when compared to the referent job strain quadrant. Unadjusted associations between the three job strain quadrants, when compared to the referent job strain quadrant, and neck-shoulder disorders were of moderate magnitude and were not statistically significant (p=0.06-0.25). Contrary to expectation, the strength of the unadjusted associations between job strain category and both neck-shoulder outcomes were similar across the three job strain categories ("high control, low demand", "low control, low demand", and " low control, high demand") when compared to the referent job strain category ("high control, low demand").

Associations between the continuous job strain ratio and neck-shoulder outcomes were not as strong as those between the continuous job strain ratio and hand-arm outcomes. Specifically the HR for the association between the continuous job strain ratio and neck-shoulder symptoms was 2.41 (p=0.30) and the HR for the association between continuous job strain ratio and neck-shoulder disorders was 5.14 (p=0.23). As noted for hand-arm outcomes, the full range of values for the continuous job strain ratio metric is less than unity and the hazard ratios are expressed per unit change of the metric.

Self reported job stress, collected weekly on a 0-10 VAS, was strongly associated with both neck-shoulder symptoms (HR=1.36, p<0.001) and neck-shoulder disorders (HR=1.31, p<0.001). Note that the hazard ratio is expressed per unit increase of weekly job stress, a metric with permissible values ranging from zero to 10. Finally, self-reported job change, also collected weekly, was strongly associated with both neck shoulder symptoms (HR=3.49, p<0.001) and neck shoulder disorders (HR=1.96, p=0.12).

Physical risk factors No statistically significant unadjusted associations were observed between the four physical risk factors and either neck-shoulder symptoms or neck-shoulder disorders (Table 12).

Multivariate models. Final multivariate models of associations between neck-shoulder outcomes and physical and psychosocial risk factors are presented in Table 13. In addition to the exposure variables listed in the table, confounding variables that were also included in each model are provided as notes to the Table. After adjustment for

confounding factors, no statistically significant elevations in risk were observed between any of the physical risk factors and either neck-shoulder symptoms or neck-shoulder disorders.

Adjusted associations between job strain quadrant category and neck-shoulder symptoms were all greater than unity (although not statistically significant) when compared to the referent category, but smaller than the comparable unadjusted associations. Conversely, adjusted associations between job strain quadrant category and neck-shoulder disorders were larger than the comparable unadjusted associations. Again, due to small cell sizes, only the association between the "low demand, low control" job strain quadrant category and hand-arm disorders was statistically significant (HR=5.61, 95%CI=1.24-25.3).

Strong and statistically significant associations between weekly stress level and neck shoulder symptoms (HR=1.31, 95% CI=1.21-1.43) and neck-shoulder disorders (HR=1.27, 95% CI=1.11-1.46) persisted after controlling for confounding. A statistically significant association between weekly job change and neck shoulder symptoms (HR=2.27, 95% CI=1.40-3.68) persisted after controlling for confounding.

DISCUSSION AND CONCLUSIONS

We conducted a prospective epidemiological study of upper extremity musculoskeletal disorders among machine-paced assembly line workers in a large manufacturing facility. Exposures to physical risk factors and occupational psychosocial factors were ascertained with objective quantitative measures prior to incident symptoms. Musculoskeletal outcomes were ascertained by questionnaire, physical examination, and when appropriate, nerve conduction measurement.

Demographics

Study participant age and gender were similar to values reported for other samples of employed persons and were representative of plant demographics. The sample was less ethnically diverse than the US workforce, however. Of relevance to interpretation of the results, study participants had been employed by the facility for 16 years and may have included a large proportion of persons who were tolerant of the work activities (i. e., the study population was distorted by selective survival).

Musculoskeletal symptom and musculoskeletal disorder incidence rates

Musculoskeletal symptoms were reported frequently by study participants. The incidence rate for hand-arm symptoms was 58 per 100 person years and the incidence rate for neck-shoulder symptoms was 54 per 100 person years. As expected, rates for disorders were considerably lower than rates for symptoms and varied by specific disorder. Specifically, the incidence rate for hand-arm disorders was 19 per 100 person years and the incidence rate for neck-shoulder disorders was 14 per 100 person years. During follow-up, the most frequent incident hand-arm disorders were carpal tunnel syndrome (8.8 per 100 person years), lateral epicondylitis (6.2 per 100 person years) and tendinitis of dorsal compartment 1 (i.e., DeQuervain's disease, 3.1 per 100 person years). The frequency of the three neck shoulder outcomes (i.e., somatic pain syndrome, rotator cuff tendinitis, and bicipital tendinitis) were similar, with rates between 9-11 per 100 person years.

Rates of musculoskeletal symptoms and musculoskeletal disorders reported in the literature vary considerably, possibly as a function of true differences across study samples and, potentially, as a consequence of differences in methods used to ascertain and report these health outcomes. For example, Punnett et al. [2004] reported a one year cumulative upper extremity symptom incidence rate of 31% among automobile manufacturing workers. *Three year* incidence rates among persons employed across numerous occupational "sectors" in France were 12.2% for carpal tunnel syndrome, 12. 2% for lateral epicondylitis, and 5.7% for wrist tendonitis [Leclerc 2001]. Smith et al. [2008] reported an incidence rate of new-onset shoulder symptoms of 23.5 per 100 person months (equivalent to 28.2 per 100 person years). Gell et al. [2005] reported an annual incidence rate of CTS among industrial and clerical workers of 1.2 per 100 person years.

Associations between musculoskeletal outcomes and physical risk factors

Few associations between physical risk factors and incident musculoskeletal symptoms and incident musculoskeletal disorders were observed. In final multivariable models, a

non-statistically significant increase of 19% per unit of HAL was observed for hand-arm disorders but not for hand-arm symptoms. No other physical risk factor was associated with hand-arm disorders. Conversely, a non-statistically significant increase of 15% per unit of HAL was observed for neck shoulder symptoms but not for neck shoulder disorders. A statistically significant seven percent increase in risk of neck shoulder disorders per unit of percent time of shoulder flexion/abduction $>90^0$ was observed. Small but statistically significant reductions in risk were observed for percent time neck flexion and percent time neck extension.

In aggregate, associations between physical risk factors and incident musculoskeletal symptoms and musculoskeletal disorders were small and, for several measures, counterintuitive in effect direction. These results were robust and were consistent with additional analyses in which 1) exposure metrics were categorized rather than included in analyses as continuous variables and 2) weekly peak exposure values were used rather than weekly TWA exposure values. In aggregate, these associations do not support a major role for physical exposures as risk factors for musculoskeletal symptoms or disorders among participants in this study.

Several methodological issues may explain these mostly negative observations. First, as noted above, the study sample was highly tenured in the study facility. The mean duration of employment among study participants was 16 years. It is possible that those employees who were most susceptible to musculoskeletal symptoms and musculoskeletal disorders had either left employment and were not available to participate in the study or had opted for jobs with lower levels of exposure, leaving only those less susceptible to these effects remaining in high exposure jobs. In addition, it is possible that the measures of exposure were not suited to capturing the biomechanically important exposures among these participants. Because of resource constraints, video and EMG samples were collected for no longer than 20 minutes per task. Longer sampling durations may have resulted in more precise estimation of exposure and less attenuation of observed associations. In addition, as noted in the Methods section, weekly time weighted averages (TWAS) were calculated for each study participant based on objective exposure to physical risk factors associated with each task and a log of daily task durations compiled by the study participant. If participants did not accurately record time spent in each task, then misclassification of weekly TWAs would result. Such misclassification would likely be independent of health status and consequently result in attenuation of observed associations in comparison to true associations, should they exist.

Finally, we note that the originally proposed exposure estimation methods did not include measures of exposure to physical risk factors other than the HAL, percent time spent in various shoulder, neck, and wrist postures, and %RVE of forearm flexor and extensor muscles and the trapezius muscle. Analyses examining associations between each of these physical exposures and musculoskeletal outcomes are presented in this report. As a consequence of the large amount of exposure information collected during the conduct of this study, other metrics of physical exposure can be constructed. For example, raw data are available to calculate values of the Strain Index, an aggregate

metric of exposure to physical risk factors originally proposed by Moore and Garg [1995]. Analyses of associations between the Strain Index and musculoskeletal symptoms and musculoskeletal disorders are currently being conducted. Preliminary findings suggest that Strain Index measures are associated with hand-arm symptoms in this cohort. These analyses are not complete and, are not included in this final report since they were not included among the originally proposed aims of the study. These analyses are mentioned to make readers aware of possible future findings from this research project.

Associations between musculoskeletal outcomes and psychosocial risk factors
Associations between psychosocial risk factors and hand-arm symptoms and hand-arm disorders were large and in the hypothesized direction. For example, a statistically significant five-fold increase in risk of hand-arm disorders was observed among participants in both "high demand, high control" and "high demand, low control" groups in comparison to the referent "low demand, high control" group. Associations between psychosocial risk factors and neck-shoulder symptoms and neck-shoulder disorders were also elevated, but less consistently so than for hand-arm symptoms and hand-arm disorders. For neither anatomical location were coworker support, supervisor support or negative affectivity associated with musculoskeletal symptoms or disorders.

A number of previous investigators have observed associations between musculoskeletal outcomes and measures of occupational psychosocial stress, although considerable inconsistency is found in the published literature. Many studies were cross-sectional and therefore susceptible to bias from cause-effect reversal. Specifically, in cross sectional studies, it may be possible for the experience of musculoskeletal symptoms to affect reporting of occupational psychosocial stress. Because information about occupational psychosocial stress was collected prior to incident musculoskeletal outcomes, such reversal was unlikely in the current study.

Another potential confounder of the association between occupational psychosocial stress and musculoskeletal outcomes in past studies is a personality trait known as negative affectivity. In particular, persons with greater negative affectivity might be expected to report higher levels of adverse experiences, including both stress and musculoskeletal discomfort. If uncontrolled, this trait alone could create the appearance of an association between psychosocial stress and musculoskeletal outcomes. As described in the methods section, a standard measure of negative affectivity, the Positive and Negative Affectivity Scale [Watson eta!., 1988, Watson and Clark, 1994, Crawford and Henry, 2004], was obtained in the current study and associations between psychosocial measures and musculoskeletal outcomes were adjusted for this metric.

yen den Heuvel et al., [2005] examined associations between psychosocial stress ascertained with the JCQ (also used in the current study) and musculoskeletal outcomes among 787 participants who were followed prospectively for three year. Significant increases in adjusted risk ratios were observed for neck-shoulder symptoms and non-significant increases were observed for distal upper extremity symptoms. Smith et al.,

[2008] examined associations observed prospectively between neck and upper extremity outcomes and psychosocial measures among 424 health care and manufacturing workers. After controlling for physical and other risk factors, participants employed in "passive" (i.e., low demand, low control) and "high strain" jobs (i.e., high demand, low control) had a doubling of risk of shoulder symptoms when compared to participants employed in "low strain" (i.e., low demand, high control) jobs. In a cross sectional study of 733 workers from 12 worksites, Silverstein et al. (2008) examined associations between physical and psychosocial risk factors and rotator cuff " syndrome". Positive but non-statistically significant effects of job strain quadrant were observed. Andersen et al. [2002] reported results of a cross sectional study of 3123 workers from 19 facilities in Denmark. Psychosocial stress was ascertained with the JCQ. Personality traits were also ascertained. High demand and low control were each were associated with increased risk of neck/shoulder pain with pressure tenderness in adjusted models.

Associations between musculoskeletal outcomes and weekly stress and weekly job change

Weekly job stress level was statistically significantly associated with all four musculoskeletal outcomes. The risk increase varied from 25 percent to 33 percent per unit of increase in weekly job stress, a metric that was collected on a 0-10 visual analog scale. To put this into perspective, participants reporting weekly job stress one standard deviation above the mean weekly job stress value (i.e., 5.4 units) had 2.6 times the risk of hand-arm disorders when compared to participants who reported weekly job stress one standard deviation below the mean weekly job stress value (i.e., 1,2 units). Elevations of risk were similar for the other three outcomes.

Job change was statistically significantly associated with hand-arm symptoms and hand-arm disorders. The risk of hand-arm disorders was more than three times greater among participants reporting a job change than among participants who did not report a job change. A statistically significant increase in neck shoulder symptoms, but not neck shoulder disorders, was also observed among participants reporting a job change. In the current facility, job change was frequently made on the basis of manufacturing need (i.e., model changes, discontinuations, etc,). We have no reason to believe that job change was the result of musculoskeletal outcomes, a phenomenon that could explain the observed association.

We are aware of only one other study in which job change was examined as a risk factor for musculoskeletal outcomes. Punnett et al. [2004] reported that a "Change in job assignment or job content appeared to confer an increased risk for development of new disorders" among automobile manufacturing workers and suggested that the observation "deserves further investigation".

Conclusions

The results of this study support a large role for psychosocial and organizational factors in the development of musculoskeletal symptoms and disorders. Methodological issues, including a highly selected study sample (average job tenure was 16 years) and a high

degree of job rotation may have resulted in underestimates of associations between musculoskeletal outcomes and exposure to physical risk factors.

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Table 1. STUDY METRICS

- Age
- Weight
- Race
- Household income
- Gender
- Height
- Education
- Hand dominance

2. Personal health
   - History of upper extremity symptoms, past three years
   - Rheumatoid arthritis and other collagen vascular disease
   - Prior upper extremity or spine disorders
   - History of trauma to the upper extremity
   - Upper extremity symptoms in the past seven days
   - Tobacco use
   - Diabetes
   - Alcoholism
   - Thyroid disease
   - Pregnancy
   - Renal failure
   - Hormone replacement therapy
3. Work history
   - Past exposure to physical workplace exposures outside facility
   - Past exposure to physical workplace exposures inside the facility
4. Occupational psychosocial stress
   - Psychological job demands, decision latitude, job strain
   - Supervisor support
   - Co-worker support
   - Positive affectivity
   - Negative affectivity
5. Work practice and work organization
   - Total hours worked per day
   - Specific assembly line worked each day
   - Specific tasks and duration of time spent performing each task each day
   - Weekly hours of aerobic activity
   - Weekly hours at second job
   - Weekly hours non-work hand-intensive work
   - Changes of job or task
   - Weekly stress level reported on a 0-10 visual analog scale
6. Forceful exertions Forearm extensor percent
   - relative voluntary exertion
   - Forearm flexor percent relative voluntary exertion
   - Trapezius Muscle percent relative voluntary exertion
7. Hand-arm repetition (Hand Activity Level)
8. Awkward postures Percent time in
   - awkward wrist posture
   - Percent time in awkward elbow posture
   - Percent time in awkward shoulder posture
   - Percent time in awkward neck posture

Table 2. Descriptive statistics of demographic and personal health characteristics (N=318)

Characteristic	Mean (SD)	N (%)
Age	43.1 (10.0)	--
Female sex	--	165 (51.9)
Height males (cm)	178.7 (9.1)	--
Height females (cm)	165.2 (6.5)	--
BMI	27.5 (5.4)	--
Education beyond High School	--	95 (29.9)
Proportion right handed	--	280 (88.1)
Non-white ethnicity	--	26 (8.2)
Annual Household Income >=$50,000	--	130 (40.9)
Hormone medication (% of women)	--	35 (21.2)
Currently pregnant (% of women)	--	1 (0.6)
Currently smoke	--	104 (32.7)
Hand outcome comorbidity	--	45 (14.2)
Past history of hand-arm pain	--	64 (21.1)
History of cervical disk disease	--	10 (3.1)
Past history of neck/shoulder pain	--	26 (8.2)
Hours per week at second job	1.1 X4.4)	--
Hours per week UE intense activities	3.7 (6.4)	--
Hours per week non-work aerobic activity	0.2 (0.4)	--
Second shift	--	84 (26.4)
Years at study worksite	15.8 (11.1)	--
Hours per week primary assembly job	31.9 (10.0)	--

Table 3. Descriptive statistics of psychosocial/work organization measures (N=318)

Characteristic	Mean	(SD)
Decision latitude ("control")	56.2	(9.8)
Psychological job demand	23.1	(3.3)
Coworker support	17.7	(2.4)
Supervisor support	14.3	(2.9)
Negative affectivity	16.5	(5.2)
Positive affectivity	31.9	(7.0)
Stress (from task log VAS)	3.3	(2.1)
Job change (N, %)	48	(15.1)

Table 4. Descriptive statistics of physical exposure variables (N=318)

Exposure Characteristic	Mean	(SD)
Hand Activity Level	4.7	(1.3)
Percent time wrist flexion (N=303)	2.8	(2.9)
Percent time wrist extension (N=303)	9.1	(7.1)
Percent time shoulder flex/abduct 60°- 90°	10.8	(8.0)
Percent time shoulder flex/abduct >90	2.4	(4.0)
Percent time neck flexion	14.6	(15.2)
Percent time neck extension	4.9	(7.0)
Forearm extensor muscle (% RVE) (N=303)	47.2	(27.3)
Forearm flexor muscle (% RVE) (N=303)	90.0	(74.5)
Trapezius muscle (% RVE)	46.1	(44.2)

Table S. Incidence and prevalence of hand-arm symptoms, hand-arm disorders, neck/shoulder symptoms and neck/shoulder disorders.

	AT ENTRY		DURING FOLLOW-UP	
CONDITION	N	Prevalence-	N	Incidence"
Hand-arm symptoms	77	19.0	100	58.0
All hand-arm disorders	45	11.8	43	19.0
Medial epicondylitis	2	0.5	4	1.8
Lateral epicondylitis	4	1.0	14	6.2
Flexor carpi radialis (FCR) Tendonitis	3	0.8	5	2.2
Flexor carpi ulnaris (FCU) Tendonitis	0	0	3	1.3
Digital flexor tendonitis	0	0	3	1.3
Dorsal compartment 1 (APL and EPB)	4	1.0	7	3.1
Dorsal compartment 2 (ECRL and ECRB)	1	0.2	2	0.9
Dorsal compartment 3 (EPL)	1	0.2	3	1.3
Dorsal compartment 4 (EDC & EIP)	1	0.2	3	1.3
Dorsal compartment 5 (EDM)	2	0.5	0	0
Dorsal compartment 6 (ECU)	5	1.3	0	0
Trigger finger	2	0.5	0	0
Carpal tunnel syndrome	26	6.8	20	8.8
Guyon canal syndrome	0	0	0	0
Neck/shoulder symptoms	65	16.8	93	53.8
All neck/shoulder disorders	29	7.6	33	14.1
Somatic pain syndrome	22	5.7	25	10.7
Rotator cuff tendinitis	11	2.9	7	9.4
Bicipital tendinitis	6	1.6	7	9.4

Percent
Per 100 person-years

Table 6. Unadjusted associations between demographic factors and hand-arm outcomes

Demographic factor	Hand-arm symptoms		Hand-arm disorders	
	Crude HR	Probability	Crude HR	Probability
Age (years)	0.99	0.59	1.01	0.51
Female sex	1.84	0.003	1.98	0.03
Height				
Lowertertile	1.45	0.11	1.43	0.32
Middle tertile	1.00	-----	1.00	- ---
Uppertertile	0.87	0.58	0.86	0.67
BMI (units)	1.01	0.53	1.09	<0.001
Education beyond HS	1.02	0.93	0.92	0.06
Right handed	0.98	0.94	0.78	0.58
Non-white ethnicity	0.83	0.63	0.61	0.49
Income >=$50,000	0.90	0.59	0.98	0.94
Current smoker	0.89	0.60	0.56	0.12
Co-morbidity (RA, DM, thyroid med. prior CTS)	1.77	0.02	2.52	0.005
Past history arm pain	3.04	<0.001	3.18	<0.001
Hours/week time in second job	1.05	0.003	1.04	0.06
Hours/week UE intensive non-work activities	1.04	0.009	0.99	0.82
Non-work aerobic activity (none vs. some)	1.19	0.43	1.20	0.57
Second shift (versus first shift)	1.12	0.65	1.14	0.74
Years worked at the study facility	0.99	0.53	1.01	0.76
Hours worked each week	1.01	0.48	1.00	0.83

Table 7. Unadjusted associations between psychosocial/work organization risk factors and hand arm outcomes

	Hand-arm symptoms			
Psychosocial risk factor	Crude HR	Probability	Crude HR	Probability
Coworker support	1.01	0.81	0.95	0.41
Supervisor support	0.95	0.19	0.98	0.77
Negative affectivity	1.02	0.23	1.02	0.46
Positive affectivity	0.99	0.32	0.96	0.09
Strain by "quadrant"				
"High control, low demand"	1.00	---	1.00	-----
"High control, high demand"	2.48	0.005	4.49	0.01
"Low control, low demand"	2.10	0.03	1.89	0.33
"Low control, high demand"	3.39	<0.001	5.48	0.002
Strain ratio Job demand/decision latitude)	11.72	0.001	9.63	0.03
Decision latitude	0.98	0.01	0.70	0.25
Job demand	1.07	0.02	3.57	<0.001
Stress (from task log VAS, time varying)	1.39	<0.001	1.31	<0.001
Job change (from task log, time varying)	4.03	<0.001	3.29	<0.001

Table 8. Unadjusted associations between physical risk factors and hand-arm outcomes

Physical risk factor	Hand-arm symptoms		Hand-arm disorders	
	HR	Probability	HR	Probability
Hand Activity Level	1.04	0.57	1.21	0.12
Percent time wrist flexion	0.96	0.29	1.00	0.97
Percent time wrist extension	1.01	0.31	0.99	0.67
Forearm extensor muscle % RVE	1.00	0.49	1.00	0.83
Forearm flexor muscle % RVE	1.00	0.82	1.00	0.51

Table 9. Final multivariate models of associations between hand-arm outcomes and physical and psychosocial risk factors

	Hand-arm symptoms		Hand-arm disorders	
Variable	HR	95% CI	HR	95% CI
Physical risk factors'				
Hand Activity Level	1.01	0.84-1.21	1.19	0.89-1.57
Percent time wrist flexion	0.96	0.88-1.04	1.01	0.91-1.13
Percent time wrist extension	1.01	0.98-1.04	0.97	0.93-1.02
Forearm extensor muscle % RVE	1.01	1.00-1.01	1.00	0.99-1.02
Forearm flexor muscle % RVE	1.00	1.00-1.01	1.00	1.00-1.01
Psychosocial risk factors'				
Job strain: "low demand, high control"	1.00	-- --	1.00	-----
Job strain: "high demand, high control"	2.25	1.11-4.55	4.99	1.33-18.7
Job strain: "low demand, low control"	2.19	1.05-4.57	2.66	0.64-11.1
Job strain: "high demand, low control"	2.59	1.27-5.28	4.94	1.31-18.7
Coworker support	1.08	0.98-1.18	1.00	0.87-1.14
Supervisor support	1.00	0.92-1.09	1.04	0.91-1.19
Negative affectivity	0.99	0.95-1.04	0.97	0.91-1.03
Weekly stress level'	1.33	1.23-1.44	1.25	1.12-1.40
Weeklyjob change°	2.38	1.49-3.80	3.35	1.64-6.86

1. Associations between physical risk factors and hand-arm symptoms controlled for all physical risk factors listed in table as well as sex, height, history of hand symptoms, job strain, weekly stress level, weekly job change, second job h/w, hand intensive activity h/w, and supervisor support.

   Associations between physical risk factors and hand-arm disorders controlled for all physical risk factors listed in table as well as sex, weeklyjob stress, BMI, comorbid conditions, and history of hand symptoms.

2. Associations between psychosocial risk factors and hand-arm symptoms controlled for all psychosocial risk factors listed in table as well as height, hand intensive activities h/w, weekly stress level, weekly job change, comorbid conditions, second job h/w, history of hand symptoms.

   Associations between psychosocial risk factors and hand-arm disorders controlled for all psychosocial risk factors listed in table history hand symptoms, BMI, comorbid conditions, weekly stress level, weekly job change, second job h/w, Hand Activity Level.

3. Associations between weekly stress level and hand-arm symptoms controlled *for* weekly job change.

   Associations between *weekly* stress level and hand-arm disorders were not confounded by any of the examined covariates.

4. Associations between weekly job change and hand-arm symptoms controlled for weekly job stress and history of hand symptoms.

   Associations between weeklyjob change and hand-arm disorders controlled forjob strain and BMI.

Table 10. Unadjusted associations between demographic factors and neck/shoulder outcomes

	Neck-shoulder symptoms		Neck-shoulder disorders	
Demographic factor	Crude HR	Probability	Crude HR	Probability
Age (years)	1.00	0.74	1.02	0.33
Female sex	2.32	<0.001	5.46	<0.001
Height				
Lowerterti le	1.45	0.14	1.27	0.57
Middle tertile	1.00	----	1.00	-----
Uppertertile	1.15	0.58	1.02	0.97
BMI (units)	1.02	0.37	1.02	0.56
Education beyond HS	1.48	0.07	1.09	0.81
Right handed	1.20	0.60	1.38	0.60
Non-white ethnicity	0.96	0.93	0.38	0.34
Income >=$50,000	1.01	0.95	0.81	0.56
Current smoker	0.97	0.89	1.12	0.76
History of disc disease	2.61	0.06	3.21	0.11
Past history neck/shoulder pain	2.07	0.02	3.76	0.002
Hours/week time in second job	1.02	0.40	1.03	0.21
Hours/week UE intensive non-work activities	1.02	0.28	1.02	0.53
Non-work aerobic activity (none vs. some)	0.97	0.91	1.02	0.72
Second shift (versus first shift)	1.27	0.32	0.35	0.08
Years worked at the study facility	0.99	0.29	1.01	0.65
Hours worked each week	0.99	0.46	1.04	0.12

Table 11. Unadjusted associations between psychosocial/work organization risk factors and neck/shoulder outcomes

	Neck/shoulder symptoms		Neck/shoulder disorders	
Psychosocial risk factor	Crude HR	Probability	Crude HR	Probability
Coworker support	0.94	0.15	0.94	0.41
Supervisor support	0.99	0.81	0.99	0.81
Negative affectivity	1.04	0.05	1.03	0.30
Positive affectivity	0.98	0.14	0.97	0.23
Strain by "quadrant"				
"High control, low demand"	1.00	-----	1.00	-----
"High control, high demand"	1.87	0.04	2.02	0.25
"Low control, low demand"	1.61	0.15	3.00	0.06
"Low control, high demand"	1.80	0.06	2.76	0.08
Strain ratio (job demand/decision latitude)	2.41	0.30	5.14	0.23
Decision latitude	0.99	0.37	0.97	0.04
Job demand	1.01	0.69	0.78	0.08
Stress (from task log VAS, time varying)	1.36	<0.001	1.31	<0.001
Job change (from task log, time varying)	3.49	<0.001	1.96	0.12

Table 12. Unadjusted associations between physical risk factors and neck/shoulder outcomes

Physical risk factor	Neck-shoulder symptom		Neck-shoulder disorder	
	HR	Probability	HR	Probability
Hand Activity Level	1.06	0.49	1.11	0.43
Percent time shoulder flex/abduct 60°-90°	1.00	0.91	1.00	0.92
Percent time shoulder flex/abduct >90^0	1.03	0.14	1.07	0.01
Percent time neck flexion	0.99	0.15	0.98	0.13
Percent time neck extension	1.01	0.52	0.99	0.59
Trapezius muscle % RVE	1.00	0.38	1.00	0.97

Table *13.* Final multivariate models of associations between neck/shoulder outcomes and physical and psychosocial risk factors

	Neck/shoulder symptom		Neck/shoulder disorder	
Variable	HR	*95%CI*	HR	*95%CI*
Physical risk factors'				
Hand Activity Level	*1.15*	*0.96-1.38*	*1.02*	*0.75-1.39*
Percent time shoulder flex/abduct *60°-90°*	*1.00*	*0.97-1.03*	*1.00*	*0.95-1.05*
Percent time shoulder flex/abduct *>90'*	*1.04*	*0.99-1.09*	*1.07*	*1.00-1.15*
Percent time neck flexion	*0.98*	*0.97-1.00*	*0.97*	*0.94-1.00*
Percent time neck extension	*0.98*	*0.95-1.01*	*0.94*	*0.88-1.00*
Trapezius muscle % RVE	*0.99*	*0.98-1.00*	*1.00*	*0.98-1.02*
Psychosocial risk factors'				
Job strain: "low demand, high control"	*1.00*	-----	*1.00*	-----
Job strain: "high demand, high control"	*1.70*	*0.86-3.36*	*3.20*	*0.74-13.9*
Job strain: "low demand, low control"	*1.42*	*0.71-2.83*	*5.61*	*1.24-25.3*
Job strain: "high demand, low control"	*1.16*	*0.58-2.34*	*3.02*	*0.72-12.7*
Coworker support	*0.97*	*0.88-1.08*	*1.03*	*0.89-1.21*
Supervisor support	*1.05*	*0.96-1.15*	*1.06*	*0.92-1.21*
Negative affectivity	*1.00*	*0.96-1.05*	*1.00*	*0.93-1.08*
Weekly stress level'	*1.31*	*1.21-1.43*	*1.27*	*1.11-1.46*
Weekly job change°	*2.27*	*1.40-3.68*	*1.18*	*0.49-2.87*

1. Associations between physical risk factors and neck/shoulder symptoms controlled for all physical risk factors listed in table as well as sex, height, education, history of neck pain, job strain, weekly job change, and weekly job stress.

   Associations between physical risk factors and neck/shoulder disorders controlled for all physical risk factors listed in table as well as sex, shift, job strain, hours worked per week, history of neck pain, and weekly job stress.

2. Associations between psychosocial risk factors and neck/shoulder symptoms controlled for all psychosocial risk factors listed in table as well as sex, education, history of disc disease, height, history of neck pain, weekly job change, and weekly job stress.

   Associations between psychosocial risk factors and neck/shoulder disorders controlled for all psychosocial risk factors listed in table as well as sex, neck posture, history of neck pain, history of disc disease, shift, and weekly job stress.

3. Associations between weekly stress level and neck/shoulder symptoms controlled for weekly job change.

   Associations between weekly stress level and neck/shoulder disorders controlled for sex.

4. Associations between weekly job change and neck/shoulder symptoms controlled for sex and weekly job stress.

   Associations between weekly job change and neck/shoulder disorders controlled for sex, shift, hours worked per week, neck posture, and weeklyjob stress.

APPENDIX

Physical examination protocols and criteria for positive examination results

APPENDIX

PHYSICAL EXAMINATION PROTOCOLS AND CRITERIA FOR POSITIVE EXAMINATION RESULTS

MUSCULOSKELETAL DISORDERS AMONG MANUFACTURING WORKERS

VERSION 2

2003

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EXAMINATION OF THE NECK

Radicular Pain Syndromes

- *Spurling's Sign* - The examiner instructs the subject to turn the head to the symptomatic side and then extend the neck. The examination is positive if the subject reports pain or paraesthesia in an anatomically defined distribution or dermatome. Localized pain at the neck indicates soft tissue pain, not pain of radicular origin. (Rosenbaum and Ochoa, 1993,. p. 61; Viikari-Juntura et al., 1989)

Criteria for diagnosis of radicular pain syndrome: Positive Spurling's sign

Somatic Pain Syndrome (Tension Neck Syndrome)

- Cervical range of motion - Record motion range for flexion/extension, lateral bending, and rotation as *abnormal* or *normal.*
- Palpation

  Sternomastoid - Palpate entire muscle for pain.

  Trapezius - Palpate muscle for trigger points or local pain.

Criteria for diagnosis of Somatic *Pain Syndrome: Any documentation of abnormal cervical range of motion* and *either* a) *Positive result for palpation of sternamastoid muscle (unilateral or bilateral) OR b) Positive result for palpation of the Trapezius muscle (unilateral or bilateral)* [Waris et al, 19791.

Thoracic Outlet Syndrome

Wright's Maneuver- Abduct and laterally rotate the affected arm, rotate the neck to the opposite side and extend the neck. A positive exam is indicated by reproduction of symptoms in the involved extremity. The examination is repeated by having the subject rotate the neck towards the affected side and flex the neck. (Leffert, 1983, p. 444)

- *Costoclovicular Compression* - With shoulder adducted, the subject is asked to position the elbow in 90 degrees of flexion. The examiner pushes the proximal forearm in a downward movement causing compression of the interval angle. A positive exam is reproduction of symptoms in the involved extremity. (AHST Clinical Assessment Recommendations 1992, p. 34).

- *Elevated Arm Extension Test (EAST)* - The subject is asked to abduct both arms to 90 deg. The subject is then asked to open and close the hands for up to 2 minutes. Reproduction of symptoms indicates a positive test. (Gerard and Kleinfield, 1993, pp. 70-71, Toomingas et al., 1991)

Provisional criteria for diagnosis *of Thoracic Outlet Syndrome: Positive Wright's* test or *Positive costoclavicular compression* test, *or Positive elevated arm extension* test *(NO SUBJECT IS TO BE EXCLUDED FROM THE STUDY FOR A DIAGNOSIS OF TOS)*

EXAMINATION OF THE SHOULDER

Rotator Cuff Tendinitis

- *Suprospinatus Point Tenderness* - With 30 deg. of shoulder extension, the examiner palpates the anterior aspect of the greater tubercle of the humerus. Resisted flexion of the elbow is used to confirm that the examiner is palpating the rotator cuff tendon and not the biceps tendon. A positive exam is recorded for localized pain or tenderness.

- *Suprospinatus Muscle Testing* - Isolate the supraspinatus muscle by having the subject abduct the arm to 90 degrees, horizontally adduct the arm by 30 degrees, extend the elbow, and maximally internally rotate the arm. The examiner then applies downward force to the distal forearm. The examination is positive when the subject reports pain on the anterior aspect of the shoulder. (Yocum, 1983, P. 287).

  Painful Arc of Motion test - Assess for a painful arc of motion by first having the subject abduct the arm to 180 degrees then adduct to a resting position at his/her side. Following completion have the subject then forward flex the arm and extend the arm back to their side. A painful arc of motion is usually noted between 70-120 degrees of motion and usually more pronounced during the eccentric phase (lowering of the arm) or extension of the arm.

Criteria for diagnosis of Rotator Cuff Tendinitis: Positive supraspinatus point tenderness and at least *one additional positive* test (i.e., *supraspinatius muscle testing, painful arc of motion* testing) [Levin and Dellon, 1992; Waris et al, 1979].

Bicipital Tendinitis

- Palpate the long head of the biceps on the anterior aspect of the humeral head for pain or point tenderness.

- *Speed's Test* - With the subject's elbow fully extended, have the subject forward flex the arm as the examiner applies resistance. The Subjects hand should be supinated. A positive test is pain or tenderness on the anterior aspect of the shoulder. (Gerard and Kleinfield, 1993, p. 130; Curtis and Snyder, 1993, p. 35; Bennett, 1996)

- *Yergason's Sign* - With the subject seated, the elbow is flexed to 90 deg. and the forearm pronated. The subject is instructed to actively supinate the forearm, flex the elbow, and externally rotate the shoulder while the examine applies resistance. Pain

at the bicipital groove indicates a positive test. (Curtis and Snyder, 1993, p. 35; Gerard and Kleinfield, 1993, p. 142, Hoppenfeld, 1976, P. 32).

Criteria for diagnosis of Bicipital Tendonitis: Positive result on palpation of the long head of *the biceps and at* least *one additional positive* test (I.e., *Yergason's* test, *Speed's Test)*

EXAMINATION OF THE ELBOW

Medial Epicondylitis

- Reverse Cozen's *Test* - The examiner palpates the medial epicondyle as the subject attempts to flex and pronate the forearm against resistance. A positive exam Is pain at the medial epicondyle. (Gerard and Kleinfield, 1993, p. 166).
- *Medial epitondyle point tenderness* - Palpate the medial epicondyle for point tenderness.
- *Medial (flexor) muscle* mass *point tenderness* - Palpate 3 or more centimeters distal to the epicondyle for pain/point tenderness.

Criteria for diagnosis of Medial Epicondylitis: Positive Reverse Cozen's Test AND a) positive medial epicondyle point tenderness OR b) positive medial (flexor) muscle mass point tenderness [Waris et *al., 1979].*

Lateral Epicondylitis

- *Cozen's Test* - With the elbow flexed, palpate the Lateral Epicondyle as the subject attempts to extend the wrist and supinate the forearm against resistance. A positive exam is pain at the lateral epicondyle. (Gerard and Kleinfield, 1993, p. 150).
- *Lateral epicondyle point tenderness.*
- Lateral *(extensor)* muscle mass *tenderness* - Palpate 3 or more cm. distal to condyle.
- *Mill's Maneuver* - With the elbow extended, the examiner passively places the the forearm into pronation and flexes the wrist. A positive examination is pain at the lateral epidondyle or the extensor muscle mass.

Criteria for diagnosis *of Lateral Epicondylitis: Positive Cozen's test OR positive Mill's Maneuver AND a) positive lateral epicondyle point tenderness OR b) positive lateral (extensor) muscle mass tenderness [Waris* et *al., 1979].*

EXAMINATION OF THE HAND

Flexor Tendons

Flexor Carpi Radialis (FCR) Tendinitis

- *Pain* on the volar radial side of the wrist with resisted radial deviation and wrist flexion.
- Point tenderness located along the FCR tendon
- *Local swelling*
- *Local warmth •*

Redness

- *Crepitance* - palpable roughness of tendon movement within the tendon sheath.

Criteria for diagnosis of Flexor Carpi Radialis Tendinitis: Positive report of pain with resistance *AND* at least *one additional positive* result (i.e., *point tenderness, local swelling, local* warmth, *redness, crepitance).*

Flexor Carpi Ulnaris (FCU) Tendinitis

- *Pain* on the volar ulnar side of the wrist with resisted ulnar deviation and wrist flexion.
- Point tenderness along the FCU tendon.
- *Local warmth*
- *Redness*
- *Crepitance* - palpable roughness of tendon movement within the tendon sheath.

Criteria for diagnosis of Flexor Carpi Radialis Tendinitis: Positive report of pain with resistance AND at *least one additional positive result (i.e., point* tenderness, *local swelling,* local *warmth, redness, crepitance).*

Digital Flexor Tendinitis

- *Pain* on resisted wrist and digit flexion
- Point *tenderness* located at the distal volar surface of the forearm
- Localswelling
- *Local warmth*
- *Redness*
- *Crepitance* - palpable roughness of tendon movement within the tendon sheath.
- Grip strength (Jaymar Dynamometer)

Criteria for diagnosis of digital flexor tendinitis: Positive report of pain AND at least one additional positive result (i.e., point *tenderness, local swelling, local warmth, redness, crepitance).*

Extensor Tendinitis

Dorsal Compartment 1 (APL & EPB)

- *Finklestein* exam - Place the subject's wrist in ulnar deviation and ask the subject to flex the thumb towards the little finger. A positive exam is pain during this maneuver. Pain should be localized on the dorsal radial aspect of the wrist.
- *Hitchikers Sign* - Resisted thumb MCP extension.
- *Localized swelling*
- *Localized tenderness*
- *Localized warmth* •

Redness

- *Crepitance*

Criteria for diagnosis of extensor tendonitis, Dorsal Compar*t*ment 1: *Positive Finkklestein* test *OR positive Hitchhiker* test.

Dorsal Compartment 2 (ECRL & ECRB)

- *Pain* on the radial side of the wrist with resisted wrist extension and radial deviation.
- Point *tenderness* at base of the index finger metacarpal (ECRL) or at the base of the long finger metacarpal (ECRB).
- *Localized warmth*
- *Redness*
- *Swelling*
- *Crepitance*

Criteria for diagnosis of dorsal compartment 2 tendonitis: Positive report of pain with *resisted wrist extension and radial deviation AND* at least *one additional positive result.*

Intersection Syndrome

- *Point tenderness* located on the dorsolateral side of the wrist proximal to the extensor retinaculum.
- *Localized swelling* proximal to the extensor retinaculum.
- *Crepitance*

Criteria for diagnosis of intersection syndrome: Positive responses on any two of the three *examination findings.*

Dorsal Compartment 3 (EPL)

- *Pain* on the dorso- radial side of wrist with resisted thumb IP extension while the MCP joint is flexed.
- Point *tenderness* •

Localized swelling •

Localized warmth •

Redness

- *Crepitance*

Diagnosis of dorsal *compartment 3 tendonitis: Pain* on resisted *thumb IP extension* AND at least one *additional positive result.*

Dorsal Compartment 4 (EDC & EIPI

- With the IPs flexed, the subject is instructed to extend and flex the MP joint for 5-10 repetitions. *Pain* on the dorsal aspect of the wrist or distal forearm with resisted digit extension while the IP joints flexed (EDC) or pain on the dorsal radial side of wrist with isolated resisted index finger extension (EIP).
- *Point tenderness* •

Localized swelling •

Localized warmth •

Redness

- *Crepitance*

Diagnosis of dorsal compartment 4 *tendonitis: Pain on resisted digit extension AND at least one additional positive result.*

Dorsal Compartment 51EDM)

- *Pain* on the dorsal ulnar side of wrist with isolated resisted small finger extension (EDM).
- *Point tenderness*
- *Localized swelling* •

Localized warmth •

Redness

- *Crepitance*

Diagnosis of dorsal compartment 5 tendonitis: Pain on resisted small finger extension AND at least one additional positive result.

Dorsal Compartment 6 (ECU)

- *Pain* on the ulnar side of wrist with resisted wrist ulnar deviation and wrist extension.
- *Point tenderness* located at the dorsal base of the fifth metacarpal. •

Localized swelling

- *Localized warmth*
- *Redness*
- *Crepitance*

Diagnosis of dorsal compartment 6 tendonitis: Pain on resisted ulnar deviation and wrist extension AND any one additional positive result.

Distal Flexor Tenosynovitis (Trigger Finger)

- Pain in the flexor tendon sheath at the Al pulley.
- *Crepitance* in the flexor tendon sheath at the Al pulley.
- Decrease *ROM* of digit due to locking in either flexion or extension.

Diagnosis of trigger finger: Positive report of pain AND a) *crepitance orb) decreased ROM.*

Carpal Tunnel Syndrome

- Report of *paroesthesia* in the median nerve distribution.
- Report of nocturnal *paroesthesio* in the median nerve distribution.
- *Phalen's Test-* The subject should be asked to position the wrist in a gravity assisted wrist flexed position for one minute. A positive exam is a complaint of paraesthesia in the median nerve distribution.
- *Tinel's Sign-* The examiner percusses with digits over the volar wrist crease area to the radial side of Palmaris Longus (Median Nerve). A positive exam is report of paraesthesias in the median nerve distribution.
- Weakness during manual muscle test of APB. •

Pinch Strength (lateral pinch).

- *Semmes- Weinstein monof(lament sensory threshold testing.* Index, long and small fingers.
- *Quantitative* Pholen's Test. Index, long, and small fingers (Koris et al., 1990).
- *Nerve Pace Distal Sensory Latency of the Median Nerve* at wrist of the affected hand.

Diagnosis of carpal tunnel syndrome: Positive report of paresthesias in the distribution of the *median nerve and positive (prolonged) distal* sensory *latency* of the *median* nerve *of the affected* hand *(with normal ipsilateral ulnar* nerve *or normal contralateral median nerve).*

Ulnar Neuritis

- Report of *paresthesias* in the distribution of the ulnar nerve.
- Using the digits the examiner percusses over Guyon's Canal. A positive exam is report of paroesthesia in the Ulnar Nerve distribution.
- Nerve Pace Distal Sensory Latency of the Ulnar Nerve at the Cubital Tunnel of the hand.
- Using the digits the examiner percusses over the cubital tunnel. A positive exam is report of *paraesthesia* in the Ulnar Nerve distribution.

• Nerve Pace Distal Sensory Latency of the Ulnar Nerve at the cubital tunnel of the affected hand.

Diagnosis of ulnar neuritis: Positive report of paresthesias in the distribution of the ulnar nerve and prolonged ulnar sensory latency.

Posterior Interosseous Nerve Entrapment

• *Pain or ache 3"distal* to *the lateral epicondyle (symptom question).*

Long finger extension test - Have the subject extend the elbow, wrist and long finger. The examiner then applies resistance downward on the long finger. Pain located at the lateral epicondyle indicates PIN entrapment. (Spinner, 1978; p.98)

Provisional criteria for diagnosis of posterior interosseous nerve entrapment: Positive response to symptom question AND positive result from long finger extension test *(NO* SUBJECT IS TO BE EXCLUDED *FROM* THE STUDY *FOR A DIAGNOSIS OF PIN).*

Anterior Interosseous Nerve Compression

• *Manual Muscle Test Flexor Pollicis Longus.* A positive result is weakness in this muscle indicating a more proximal median nerve compression problem or AIN compression. A positive exam is a muscle grade less than 5/5. (0/5 - 4/5)

Criteria for diagnosis of anterior interosseous nerve *compression: Positive manual muscle* test *Flexor Pollicis Longus. (NO* SUBJECT IS TO BE EXCLUDED *FROM THE STUDY FOR A DIAGNOSIS OF AIN)*

Pronator Syndrome

• *Manual muscle* test *of the pronator teres muscle:* The examiner applies resistance as the subject attempts to pronate the forearm. Pain is located in the pronator muscle area. (Median Nerve paraesthesias are also often present)

Provisional criteria for diagnosis of Pronator Syndrome: Positive manual muscle test *of the pronator* teres *muscle (NO SUBJECT IS TO* BE EXCLUDED *FROM* THE *STUDY FOR A DIAGNOSIS OF PS)*

Appendix

Point tenderness is found positive by comparing tenderness with a normal or asymptomatic tendon. If symptomatic tendon subjectively feels different to subject than asymptomatic tendon then it is described as a positive finding.

CASE DEFINITIONS FOR MUSCULOSKELETAL DISORDERS

NECK/SHOULDER

Radicular pain syndrome Positive neck compression test (i.e., Spurling's sign)[Ellenberg et al., 1994; Viikari-Juntura et al., 1989; Gross et al., 1996].

Somatic pain syndrome Abnormal cervical range of motion and pain on palpation of either a) Sternomastoid muscle (unilateral or bilateral) or b) Trapezius muscle (unilateral or bilateral) [Waris 1979].

Rotator cuff tendinitis Positive supraspinatus point tenderness and a) positive supraspinatius muscle test (Yocum, 1983] orb) painful arc of motion test [Levin and Dellon, 1992; Chard et al., 1988].

Bicipital tendinitis Point tenderness on palpation of the long head of the biceps and either positive Speed's test [Gerard and Kleinfield, 1993; Curtis and Snyder, 1993; Bennett 1996; Post, 1988; Waris, 1979]or positive Yergason's test [Gerard and Kleinfield, 1993; Curtis and Snyder, 1993; Bennett 1996; Post, 1988; Waris, 1979, Hoppenfeld, 1976].

HAND-ARM

Medial epicondylitis Positive Reverse Cozen's Test [Gerard and Kleinfield, 1993] and a) positive medial epicondyle point tenderness orb) positive medial (flexor) muscle mass point tenderness [Waris, 1979].

Lateral epicondylitis a) Positive Cozen's test [Gerard and Kleinfield, 1993] or positive Mill's maneuver [Gerard and Kleinfield, 1993] and b) positive lateral epicondyle point tenderness or positive lateral (extensor) muscle mass tenderness [Hoppenfeld, 1976; Thomson and Szabo, 1989; Viikari-Juntura E, 1984].

Flexor carpi radialis tendinitis Pain at the volar radial side of the wrist with resisted radial deviation and wrist flexion and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance [Cailliet, 1994; Tubania et al., 1996].

Flexor carpi ulnaris tendinitis Pain at the volar ulnar side of the wrist with resisted ulnar deviation and wrist flexion with resistance and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance (Cailliet, 1994; Tubania et al., 1996).

Digital flexor tendinitis Pain at the palmar wrist with resisted wrist and digit flexion and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance [Thomson and Szabo, 1989; Cailliet, 1994].

Extensor tendinitis - dorsal compartment I (abductor pollicis longus & extensor pollicis brevis) Positive Finklestein test [Gross et al., 1996; Cailliet, 1994; Tubania et al., 1996; Moore, 1997] or pain on resisted thumb MCP extension (Hitchhiker test).

Extensor tendinitis - dorsal compartment 2 (extensor *carpi radialis longus & extensor carpi radialis brevis)* Pain on the dorsum of the hand at the base of the second and third metacarpal with resisted wrist extension and radial deviation and one or more of the following findings: point

tenderness, local swelling, local warmth, redness, or crepitance [Gross et al., 1996; Thomson and Szabo, 1989; Tubania et al., 1996].

Intersection syndrome Two of the following three findings: point tenderness located on the dorsolateral side of the wrist proximal to the extensor retinaculum, localized swelling proximal to the extensor retinaculum, crepitance.

Extensor tendinitis - dorsal compartment 3 (extensor pollicis longus) Pain on resisted thumb IP extension and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance (Gross et al., 1996; Thomson and Szabo, 1989].

Extensor tendinitis - dorsal compartment 4 (extensor digitorum communis (EDC] & extensor indicis propriis (EIP]) With the IPs flexed, the subject is instructed to extend and flex the MP joint for 5-10 repetitions. Pain on the dorsal aspect of the wrist or distal forearm with resisted digit extension with the IP joints flexed (EDC) or pain on the dorsal radial side of wrist with isolated resisted index finger extension (EIP) and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance [Gross et al., 1996; Thomson and Szabo, 1989].

Extensor tendinitis - dorsal compartment 5 (extensor digiti minim!) Pain on the dorsal ulnar side of wrist with isolated resisted small finger extension (EDM) and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance [Gross et al., 1996].

Extensor tendinitis - dorsal compartment 6 (extensor carpi ulnaris) Pain on the dorsal ulnar side of the wrist with resisted ulnar deviation and wrist extension and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance (Gross et al., 1996; Thomson and Szabo, 1989].

Distal flexor tenosynovitis (trigger finger) Pain in the flexor tendon sheath at the AI pulley and either crepitance in the flexor tendon sheath at the AI pulley or decrease ROM of digit due to locking in either flexion or extension [Waris 1979; Thomson and Szabo, 1989; Cailliet, 1994].

Carpal tunnel syndrome Paresthesias in the distribution of the median nerve and prolonged sensory latency (3.2 ms. at 14 cm distance) of the median nerve across the affected wrist [Rempel et al., 1998; Cailliet, 1977; NeuMed, 1998].

Ulnor neuritis Paresthesias in the distribution of the ulnar nerve and prolonged sensory latency (3.2 ms. at 14 cm distance) of the ulnar nerve (NeuMed, 1998; Dawson et al., 1990].

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