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USING THE STRAIN INDEX AND TLV FOR HAL TO PREDICT INCIDENCE OF AGGREGATE DISTAL UPPER EXTREMITY DISORDERS IN A PROSPECTIVE COHORT

by

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ABSTRACT

USING THE STRAIN INDEX AND TLV FOR HAL TO PREDICT INCIDENT OF AGGREGATE DISTAL UPPER EXTREMITY DISORDERS IN A PROSPECTIVE COHORT

by

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The University of Wisconsin-Milwaukee, 2012
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Work-related distal upper extremity (DUE) musculoskeletal disorders (MSDs) are very prevalent and costly in the United States. It is important to recognize working conditions that lead to these disorders, in order to lessen the impact that they have on workers and their employers. Identifying jobs that are likely to cause DUE MSDs is difficult because there are many factors that are believed to contribute to DUE MSD development. The current study aims to determine if the Strain Index (SI) and the ACGIH TLV for HAL (two DUE job physical exposure assessment methods) predict increased risk of workers developing aggregate DUE MSDs. For this study, aggregate disorders include: (i) carpal tunnel syndrome, (ii) lateral epicondylitis, (iii) medial epicondylitis, (iv) tendonitis of wrist flexors and extensors, (v) de Quervain's disease, and (vi) trigger finger.

Subjects for this study were drawn from a recently completed large-scale prospective cohort study consisting of 1,205 volunteer workers from 21manufacturing companies located in IL, UT, and WI. Of the 1,205 workers, only those workers who had no previous history of an aggregate disorder at study onset will be considered. Workers were followed monthly to determine if new DUE MSD symptoms developed. Specific case definitions are used to identify when a worker develops one or more aggregate DUE

MSD. Physical exposures from workers' jobs were individually measured and videos were recorded at baseline. Jobs were investigated quarterly to determine physical exposure changes and re-analyzed as necessary. Time to first aggregate DUE MSD was modeled using proportional hazards regression to determine if there is a relationship between SI and TLV for HAL scores and increased risk of developing DUE MSDs while controlling for relevant covariates (age, gender, BMI).

Univariate analyses, showed a strong relationship between age (HR = 1.03, $p = 0.001$) and gender (HR = 2.38, $p = 0.002$) and the development of aggregate DUE MSDs. There was suggestive evidence that the SI, with a cut point of 6.1 ($p = 0.13$), predicts increased risk of first lifetime aggregate DUE MSD. No significance was noted for the TLV for HAL. Efforts per minute showed a slightly significant association using a spline placed at 37.3 ($p = 0.03$). Multivariate analyses found suggestive evidence for an association between efforts per minute when analyzing using a spline placed at 37.3 efforts per minute (p = 0.08).   No effect was found with the SI or TLV for HAL.

Age and gender appear to be significantly associated with the development of first lifetime DUE MSD. The SI appears to be a more reliable method to use to determine jobs that place workers at increased risk of developing first lifetime aggregate DUE MSD, when comparing it to the TLV for HAL.

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Despite great attention from researchers and practitioners, work-related musculoskeletal disorders (WMSDs) remain common and costly to industry. In 1996, the National Institute for Occupational Safety and Health (NIOSH) estimated the cost to be $13 billion annually, in 1997 the American Federation of Labor and Congress of Industrial Organizations (AFL-CIO) estimated it to be $20 billion annually, and in 2001 the National Research Council and the Institute of Medicine estimated it to be from $45 to $54 billion annually. In 2008, it was estimated that WMSDs cost U.S. industry $53.42 billion in direct U.S. workers compensation costs, annually. (Liberty Mutual Workplace Safety Index, 2010) According to the most recent Bureau of Labor Statistics report (2010) there were 284,340 work-related musculoskeletal disorders (WMSDs) in the United States. Of these, 78.2% resulted in lost time. The most often injured body region is the back, contributing 47% of all injuries, followed by distal upper extremity with 14.4% and shoulder with 13.3% (BLS, 2010). The occupations with the highest incidence of WMSDs occur in service occupations (70,780), followed by transportation and material moving occupations (58,060), and then production occupations (33,280). The incident rate for WMSDs was 34 cases per 10,000 full-time workers in 2010 and this number has remained virtually unchanged from the last 20 years. (Bureau of Labor Statistics, 2010, 2008, 2000)

WMSDs are also costly to workers, commonly creating a loss in income for injured workers, mostly due to days missed from work. (Spreeuwers, de Boer Verbeck, van Beurden, de Wilde, Braam, Willemse, & van Dijk, 2011) According to the Bureau of

Labor Statistics (2010), lost time WMSDs averaged 10 days away from work annually. For the distal upper extremity (DUE), hand/wrist injury in general resulted in 14 lost days, with more prevalent disorders, such as carpal tunnel syndrome (CTS) and tendonitis resulting in 27 and 15 lost days on average, respectively.

Employers with frequent and/or severely injured workers often suffer losses in productivity and worker skill. For example, Martimo, Shiri, Miranda, Ketola, Varonen, & Viikari-Juntura (2009), found that 56% of workers with an upper extremity disorder reported a productivity loss, with an average reduction in productivity of about 34%. A study by Keogh, Nuwayhid, Gordon, & Gucer (2000) found that 53% of patients who had acquired a work-related DUE MSD and who had claimed compensation, reported persistent symptoms that were severe enough to interfere with work during four years post-claim, leading to a loss in productivity for the employer.

WMSDs have a complex, multi-factorial etiology (Bernard, 1997), including individual risk factors (e.g. age, gender, BMI, etc.), psychosocial factors (e.g. job satisfaction, job control, etc.), and job physical exposure (e.g. force, frequency, etc.). Various job analysis methods have been developed that attempt to address the multi-factorial etiology of WMSDs. However, none have been completely validated and all have limitations.

This study quantifies job physical exposures using the SI and TLV for HAL to determine if physical exposure is associated with increased risk of aggregate DUE MSDs while controlling for age, gender, and obesity (measured using body mass index (BMI)).

The study’s specific hypothesis is that there is a relationship between scores of (i) the Strain Index (SI) and (ii) the American Conference of Governmental Industrial Hygienists Threshold Limit Value for Hand Activity Limit (TLV for HAL) and incidence of aggregate upper extremity disorders.

Literature Review

Epidemiological Studies of DUE MSDs

This study considers CTS, lateral epicondylitis, medial epicondylitis, hand/wrist flexor and extensor tendonitis, de Quervain's disease, and trigger finger as aggregate DUE MSDs. The Occupational Safety and Health Administration (OSHA) defines MSDs as "disorders of the muscles, nerves, tendons, ligaments, joints, cartilage and spinal discs." They specify that MSDs "do not include disorders caused by slips, trips, falls, motor vehicle accidents, or other similar accidents." The following summaries are of the etiology and diagnosis criteria of the specific aggregate disorders, followed by landmark studies that describe specific risk factors for each disorder.

Carpal Tunnel Syndrome. CTS is an entrapment neuropathy that is caused by the compression of the median nerve as it passes through the carpal tunnel of the wrist. This compression is caused by increased intra-tunnel pressure. (Herbert, Gerr, & Dropkin, 2000) Signs and symptoms include: (i) numbness/tingling in two or more median nerve served digits (1-4) and (ii) an abnormal nerve conduction study (NCS) (Harrington, Carter, Birrell, & Gompertz, 1998).

A study by Silverstein, Fine, & Armstrong (1987) analyzed risk factors for CTS with 652 workers from 7 different industrial sites. The workers were classified into four groups based on their level of physical exposure: high force-high repetitiveness, high force-low repetitiveness, high repetitiveness-low force, and low force-low repetitiveness. The authors found that the prevalence for CTS ranged from 0.6% among workers in low force-low repetitive jobs to 5.6% among workers in high force-high repetitive jobs. With gender, age, and years on the job analyzed as confounders, the authors found that CTS was strongly associated with high force-high repetitive jobs (OR = 15.5, $p < 0.001$) when compared to low force-low repetitive jobs. In addition the authors found, to a lesser extent, low force-high repetitive jobs (OR = 2.7) and high force-low repetitive jobs (OR = 1.8) to be associated with CTS, but not statistically significant. The authors found that repetitiveness appeared to be a stronger risk factor than force (OR = 5.5, $p < 0.05$). Gender, age, and years on the job were not statistically significant. Therefore, jobs that include high efforts per minute or high efforts per minute and a high intensity of exertion are risk factors for CTS.

Though considered a landmark study for determining risk factors associated with CTS, Silverstein, et. al. (1987) has a couple weaknesses. One limitation is that the study was retrospective, relying on subject recall of date of onset to determine if the CTS had originated while participating in the study. Subject recall is not a highly reliable method of determining CTS prevalence. Another limitation is that survivor/selection bias occurred due to only accepting active workers with at least one year on the job, in order to exclude workers with less seniority because they may have brought CTS previously obtained on another job to the one under study. This may have excluded the workers with less seniority, who had acquired CTS during the study, which would decrease the study's CTS prevalence. Another limitation is that NCSs were not used for the diagnosis of CTS, which could have led to an overestimation of CTS prevalence.

A study by Violante, Armstrong, Fiorentini, Graziosi, Risi, Venturi, Curti, Zanardi, Cooke, Bonfiglioli, & Mattioli (2007) assessed risks associated with work-related biomechanical overloads in the onset and course of CTS. To accomplish this, the authors evaluated 2,092 workers in work-groups with job tasks spanning different biomechanical exposures at baseline in terms of ACGIH hand-activity/peak force action limit and TLV. The authors found that one-year incidence of CTS symptoms was 7.3%. “Unacceptable” overload was associated with a 3-fold increased risk of onset of CTS symptoms as compared to “acceptable” load. Workers who experienced “borderline overload” appeared to be associated with a 1.5-fold increase in risk. Female gender was a stronger risk factor among exposed workers (OR = 7.3, in workers with “unacceptable overload”, OR = 6.7, in “borderline overload” vs OR = 2.5 in “acceptable load”). Being overweight/obese appeared to be an independent risk factor among exposed workers (OR = 1.9 in workers with “unacceptable” overload, OR = 1.7 to 2.8 for “borderline” overload vs OR = 1.1 to 1.5 in “acceptable load”). Therefore, the authors came to the conclusion that risk factors for CTS are jobs that require a biomechanical overload. They also found the female gender and increased BMI to be risk factors.

The Violante, et al. (2007) study has multiple strengths and a few limitations. A strength of the study is that the authors used an agreed upon case definition and NCSs to determine CTS diagnosis, in order to be confident in the diagnoses. Additionally, a large cohort of workers was used in a broad range of occupations, which makes the results generalizable. However, the authors did not break down the type of physical exposures seen on the job, so the reader does not know more about the specific type of exposures that led to the development of CTS.

Lateral Epicondylitis. Lateral epicondylitis is caused by a lesion at the common extensor origin of the lateral epicondyle of the humerus. (Harrington, et. al., 1998) In addition to lesions, vascular hyperplasia and active fibroblasts can also occur at the common extensor origin of the lateral epicondyle, which contributes to the development of this disorder (Van Hofwegen, Baker, & Baker, 2010). Vascular hyperplasia and active fibroblasts are the pathologic healing response to microtears caused by repetitive eccentric or concentric overloading of the extensor muscle mass. (Van Hofwegen, et al., 2010) Signs and symptoms for lateral epicondylitis are: (i) lateral elbow pain, (ii) pain upon palpation of one or more of six lateral tender points, and (iii) a positive resisted wrist extension test, which is a maneuver of bending the wrist backward against resistance (extension) causing pain for those with lateral epicondylitis (Harrington, et. al., 1998).

A case-referent study by Haahr & Andersen (2003) suggests that physical exposure factors are associated with lateral epicondylitis. The authors compared 267 new cases of lateral epicondylitis to 388 referents and found that manual job tasks (OR = 3.1, 95% CI = 1.9 – 5.1), self-reported "posture", (arms lifted away from body: males OR = 2.1, 95% CI = 1.1 – 4.3, females OR = 4.4, 95% CI = 2.3 – 8.3; hands bent or twisted: males OR = 3.2, 95% CI = 1.5 – 6.9, females OR = 10.0, 95% CI = 4.1 – 22.4) and "forceful work" (males OR = 2.2, 95% CI = 1.3 – 3.9, females OR = 2.8, 95% CI = 1.6 – 5.0) were related to lateral epicondylitis. The authors also found that among females, work involving performing repeated movements of the arms was related to lateral epicondylitis (OR = 3.7, 95% CI = 1.7 – 8.3). Among males, the authors found that work with precision demanding movements was related to lateral epicondylitis (OR = 5.2, 95% CI = 1.5 – 17.9). An index was established based on posture, repetition, and force. The adjusted ORs for lateral epicondylitis at low, medium, and high index values were 1.4 (95% CI = 0.8 – 2.7), 2.0 (95% CI = 1.1 – 3.7), and 4.4 (95% CI = 2.3 – 8.7). The authors conclude that physical exposure factors, such as manual job tasks, posture, intensity of exertion, efforts per minute, and work requiring precision movements are risk factors for lateral epicondylitis.

One limitation of the Haahr & Andersen (2003) study is that selection bias occurred due to the recruitment of only cases attending general practice. These patients may be those with more severe symptoms or those experiencing the greatest problems in performing their activities of daily living. In addition, an information bias could have occurred due to information on job exposure having been collected by questionnaire, which obtains limited and subjective information.

Medial Epicondylitis. Similar to lateral epicondylitis, medial epicondylitis is caused by a lesion at a common muscle group origin, but medial epicodylitis occurs at the medial epicondyle of the humerus, where the flexor wrist and hand muscles originate. (Harrington, et. al., 1998) The pathologic healing responses, mentioned with lateral epicondylitis, of vascular hyperplasia and active fibroblasts, can also occur with this disorder (Ciccotti, Schwartz, & Ciccotti, 2004). Signs and symptoms required for the diagnosis of medial epicondylitis are: (i) medial elbow pain, (ii) pain upon palpation of one or more of two medial tender points, and (iii) positive resisted wrist flexion, which is a maneuver that includes flexing the wrist against resistance which causes pain at the medial aspect of the elbow for individuals with the disorder (Mani & Gerr, 2000).

Descatha, Leclerc, Chastang, Roquelaure, & the Study Group on Repetitive Work (2003) analyzed medial epicondylitis independently and its links between individual and occupational risk factors in repetitive work, using a cross-sectional design. The authors used 1,757 workers for the study, who were examined by an occupational health physician during one year and 598 workers were again examined three years later. The authors found that the prevalence for medial epicondylitis was between 4 and 5%, with an annual incidence estimate at 1.5%. The authors determined that forceful work was a risk factor (OR = 1.95, $p = 0.01$), but not exposure to repetitive work. The authors found that workers diagnosed with medial epicondylitis had a significantly higher prevalence of other WMSDs (at least one WMSD, $p < 0.001$). Therefore, a high intensity of exertion and the prevalence of other WMSDs increase risk of developing medial epicondylitis.

The Descatha, et. al. (2003) study used a cross-sectional design, which is a weaker design because the reader is not able to infer the temporal sequence between the exposure and the disorder. These studies also are of a weaker design because they only include current and not former workers; therefore, the results may be influenced by the selective departure of workers who had already acquired a DUE MSD. Due to the study's design, a possible selection bias could have occurred in two ways: (i) more occupational physicians from the firms with higher prevalence of upper-limb disorders participated in the follow-up component of the study (which would have increased the prevalence rate) and (ii) 102 workers were lost to follow-up (it is uncertain what happened with these participants).

Shiri, Viikari-Juntura, Varonen, & Heliövaara (2006), attempted to estimate the prevalence of lateral and medial epicondylitis and to investigate their risk factors. This study analyzed 4,783 participants. The authors found the prevalence of definite lateral epicondylitis was 1.3% and that of medial epicondylitis was 0.4%. They found that the prevalence did not differ between men and women and was highest in subjects aged 45-54 years. The authors found an interaction between repetitive movements of the arms and forceful activities for the risk of possible or definite lateral epicondylitis (for both repetitive and forceful activities vs. no such activity: OR = 5.6, $p = 0.002$). The authors found that women's obesity (OR = 2.7, 95% CI = 1.2 – 6.0), repetitive movements of the arms among women (OR = 1.7, 95% CI= 1.0 – 2.9), and forceful activities among men (OR = 2.2, 95% CI = 1.0 – 4.7) independently of each other showed significant associations with medial epicondylitis. Therefore, the authors found different risk factors for each disorder. Risk factors for lateral epicondylitis include jobs that require both a high amount of efforts per minute and a high intensity. Risk factors for medial epicondylitis include women's obesity, efforts per minute among women, and high intensity exertions among men. The authors conclude that physical exposure is a risk factor for both lateral and medial epicondylitis.

A limitation of the Shiri, et al. (2006) study is that it is a cross-sectional design. In addition, the prevalence of epicondylitis may have been underestimated and the estimated odds ratios may have been lessened because the subjects who were not included in the study were more frequently exposed to forceful activities than those included in the study.

Hand/Wrist Flexor and Extensor Tendonitis. Tendonitis is caused by forces that exceed the ability of tendinous tissue to adapt, which causes the tendon(s) to become inflamed. (Piligian, Herbert, Hearns, Dropkin, Lansbergis, & Cherniack, 2000) Tendonitis of the hand/wrist extensors is caused by inflammation of an extensor tendon and tendonitis of the flexors is caused by inflammation of a flexor tendon. Tendonitis of the hand/wrist extensors is diagnosed by noting the following signs and symptoms: (i) dorsal wrist pain, (ii) 2-6 extensor compartment tenderness (dorsal wrist area), and (iii) pain worsened by resisted wrist or finger extension. Tendonitis of the hand/wrist flexors is diagnosed by noting these signs and symptoms: (i) volar wrist pain, (ii) no numbness/tingling in digits 1-4, (iii) three locations of digital flexor tendon tenderness, and (iv) positive resisted wrist flexion, which is positive if it elicits pain. (Mani & Gerr, 2000; Pilgian, et. al., 2000)

Silverstein, Fine, & Armstrong (1986) analyzed forceful and repetitive job attributes to determine whether they were positively associated with cumulative trauma disorders (CTDs). The authors describe CTDs as tendon-related disorders of the hand and wrist that produce inflammation of the tendons or compression of the peripheral nerves. Hand/wrist tendinitis is often considered a CTD. The authors analyzed a total of 574 workers from six different industrial sites that were categorized into four force repetitive exposure groups. Significant positive associations were observed between hand wrist CTDs and high force-high repetitive jobs (OR = 30.3, $p < 0.0001$), which were independent of age, gender, years on the job, and plant. When force (low, high), independent of repetitiveness, was entered into the model as the only exposure measure, the odds ratio for high force was 4.4 ($p < 0.0001$). When repetitiveness (low, high), irrespective of force, was entered into the model as the only exposure variable, the odds ratio was 2.8 ($p < 0.005$). This study demonstrates that exertion intensity and efforts per minute, together and independently, are risk factors for developing flexor or extensor hand/wrist tendinitis.

A limitation of the Silverstein, et. al. (1986) article is that the results may have underestimated the prevalence of hand wrist CTDs, due to subject selection being limited to active workers. Additionally, the one year seniority criteria for subject selection excluded those who might have had CTDs and transferred before one year, as well as those with CTDs but were not on the job for at least one year.

A longitudinal study by Leclerc, Landre, Chastang, Niedhammer, Roquelaure, & the Study group on Repetitive Work (2001) analyzed individual and physical exposure risk factors associated with the development of wrist tendonitis. The authors used 598 workers in five activity sectors. The participants were given questionnaires and a physical exam, once in two consecutive years, and then again three years later. The authors found that the presence of somatic problems (3.78, $p \geq 0.15$) and social support at work (OR = 2.49, $p \geq 0.15$) was a strong predictor of wrist tendinitis. They also found that a BMI increase of ≥ 2 kg/m^2 (OR = 2.2, $p \geq 0.15$) was associated with the incidence of wrist tendinitis. Additionally, the authors found that workers, who reported that they had to repetitively hit during work (OR = 2.16, $p \geq 0.15$), were associated with a higher incidence of wrist tendonitis. Therefore, somatic problems, lack of social support, increased BMI, and repetitively hitting an object during work were risk factors for wrist flexor or extensor tendinitis.

Although Leclerc, et. al. (2001) study points out important possible risk factors associated with the development of wrist tendonitis, it has some limitations. The authors note that they had difficulty interpreting results about the incidence of specific disorders in a group in which many workers are already affected at the beginning. This is due to the fact that the “healthy” workers at baseline represented a select group, since they were unaffected despite a high level of occupational exposure. Another limitation is that the temporal aspects of causality are unknown. The authors did not know the time lag between occupational exposure and the onset of the upper-limb disorder. Therefore, it is more difficulty to develop a cause and effect relationship between the exposure and the disorder.

De Quervain's Disease. De Quervain's disease is caused by thickening of the fibrous sheath or retinaculum in the first dorsal extensor compartment. (Barton, Hooper, Noble, & Steel, 1992) The first extensor compartment is located where the extensor pollicis brevis and the adductor pollicis longus are housed. Signs and symptoms required to diagnose de Quervain's disease are: (i) radial wrist pain centered over the radial styloid, (ii) first extensor compartment tenderness (base of thumb), and (iii) a positive Finkelstein test, which is a maneuver that includes positioning the person's thumb within their flexed fingers and then the hand is manipulated into ulnar deviation (test is positive if radial wrist pain or tenderness is elicited). (Harrington, et. al., 1998; Mani & Gerr, 2000; Witt, Pess, & Gelberman, 1991)

Moore (1997) reviews information from the medical literature on occupational risk factors associated with the development of De Quervain's tenosynovitis. The author noted that De Quervain's disease tends to appear more in females than in males and primarily between the ages of 35 and 55. The review notes that cases tend to appear more in individuals who use their thumbs a great deal. Also, cases tend to appear more with workers who complete fast, repetitive manipulations, or where the posture of the hand was such that unremitting, or repetitive pinching, grasping, pulling, or pushing was necessary. Therefore, gender manual work that involves the thumb, efforts per minute, and posture may be risk factors for de Quervain's disease.

Moore (1997) also notes limitations that appear in the literature regarding de Quervain's disease. One limitation is that few epidemiological studies exist that focus specifically on de Quervain's tenosynovitis. Moore (1997) goes on to note that there are no studies that establish or fail to confirm an association between hand usage, including hand usage at work, and de Quervain's as a specific disorder. Therefore, more research needs to be conducted to determine true risk factors for de Quervain's disease.

A cross-sectional study by LeManac'h, Roquelaure, Ha, Bodin, Meyer, Bigot, Veaudor, Descatha, Goldberg, & Imbernon (2011) analyzed personal and occupational risk factors for De Quervain's disease in a working population of 3,710 workers. Of these participants, 45 workers were diagnosed with De Quervain's disease by physical examination. A standardized physical and a self-administered questionnaire were used to assess individual factors and work exposure. The authors found that the prevalence rates of De Quervain's disease for the whole working population was 1.2%. The personal risk factors that they found for De Quervain's disease were age (OR = 1.1 for 1-year increase with age, $p = 0.001$) and female gender (OR = 4.9, $p = <0.001$). The work-related factors, that the authors found, were workpace dependent on technical organization (OR = 2.0, $p = 0.045$), repeated or sustained wrist bending in extreme posture (OR = 2.6, $p = 0.010$), and repeated movements associated with the twisting or driving of screws (OR = 3.4, $p = 0.001$). This study demonstrates that age, gender, technical organization, repeated or sustained wrist bending in extreme posture, and repeated twisting or driving of screws are risk factors for de Quervains disease.

LeManach'h, et al. (2011) has a few limitations. One limitation of the LeManach'h, et. al. (2011) study is that the authors did not exclude participants who have been diagnosed with osteoarthritis or hand/wrist tendinitis. This may have led to an overestimation of the amount of workers who actually had De Quervain's disease.

Additionally, a healthy worker effect may have occurred, due to the study's cross sectional design, which may have led to an underestimation of the estimates of risk.

Trigger Finger. Trigger finger is caused by hypertrophy of the retinacular sheath and peritendinous tissue in the volar aspect of the hand or swelling of the finger tendon, which progressively restricts the motion of the flexor tendon. (Newport, Lane, & Stuchin, 1990; Rozental, Zurakowski, & Blazar, 2008; Sampson, Badalamente, Hurst, & Seidman, 1991) Thickening of the sheath, along with some localized tendon thickening, may create a narrowed tunnel for tendon excursion and lead to a block in movement. Trigger finger typically occurs at the site of the A1 pulley, which is located around the area of the metacarpalphalangeal (MCP) joints (Akhtar, Bradley, Quinton, & Burke, 2005). Signs and symptoms for the diagnosis of trigger finger are: (i) pain in the finger and focal tenderness over A-1 pulley, and (ii) demonstrated triggering (a catching of a digital flexor tendon as it glides under the A-1 pulley. (Makkouk, Oetgen, Swigart, & Dodds, 2008; Mani & Gerr, 2000)

There have been few studies that address the etiological factors associated with trigger finger. Trezies, Lyons, Fielding, & Davis (1998) investigated the occupational histories of 178 patients with diagnosed trigger finger. The authors used a questionnaire that asked about each patient's employment during the last 10 years and then the authors divided their occupations were divided up into one of four categories: (i) unemployed/housewife/retired, (ii) office work, (iii) light manual, and (iv) heavy manual. The authors compared the histories with the 1991 Census data and found that the distribution of their occupations was not significantly different from the local general population, meaning that trigger finger appears to be unrelated to work.

The results from Trezies, et al. (1998) may not be reliable due to multiple study limitations. A questionnaire was used to gather participant information, which is a subjective way of acquiring information and may not be very reliable or accurate. Additionally, the four exposure groups were classified in very generic categories, which could encompass many different tasks. Therefore, physical exposure may have varied greatly within each category, which would make the results less accurate.

There have been a few articles that list possible risk factors associated with the development of trigger finger, but do not provide any direct evidence of associations. An article by Thorson & Szabo (1989) reports that possible occupational factors that may lead to the development of trigger finger are repetition while in in non-neutral posture, vibration, low temperature, pressure from hard objects, forceful blows, or torques. Another article by Rosenthal (1987) suggests that osteoarthritis, using vibrating tools, sustained and repetitive grasps, repetitive crimping, use of small tools, or a significant change in the customary pattern and exceptional level of hand activities may be related to the development of trigger finger.

The above studies demonstrate three main groups of risk factors that need to be considered when analyzing DUE MSDs: (i) physical (force, frequency, posture, etc.), (ii) psychosocial (increased stress, limited job satisfaction, etc.), and (iii) individual (age, gender, BMI, etc.). Most job analysis methods use physical risk factors to estimate level of risk associated with the job. However, there is ample evidence in the literature that suggests individual risk factors are associated with the development of DUE MSDs. Psychosocial risk factors are often mentioned as risks, but little evidence is available showing these factors as predictors of DUE MSDs.

In summary of the above studies, physical risk factors appear to have a great amount of evidence to support their relationship with the development of DUE MSDs. A study by Melchior, Roquelaure, Evanoff, Chastang, Ha, Imbernon, Goldberg, Leclerc, and the Pays de la Loire Study Group (2006) analyzed the role that physical risk factors have on the development of upper extremity MSDs among 2,656 workers. The authors compared manual and non-manual workers. Among physical risk factors, the authors found that repetitive movements, forceful movements, exposure to vibrations, and wrist flexion to be significant ($p < 0.0001$). Additionally, a study by Moore, Rucker, & Knox (2001) analyzed 56 jobs in order to determine the impact of various physical risk factors on DUEs. They found repetition, gloves, and forcefulness to have an odds ratio (OR) of ≥ 9.0, $p \leq 0.01$. The authors also found several significant interactions among physical risk factors, which include interactions among high repetitiveness and high forcefulness (OR = 27.0, $p < 0.001$), and high forcefulness and non-neutral posture (OR = 3.3, $p = 0.03$). Several studies have provided evidence that force (Descatha, et al. (2003); Haahr & Andersen (2003); Melchior, et al. (2006); Moore, et al. (2001); Shiri, et al. (2006); Silverstein (1987); Silverstein, et al. (1986)), repetition (Haahr & Andersen (2003); Melchior, et al. (2006); Moore, et al. (2001); Shiri, et al. (2003); Silverstein, et al., (1987); Silverstein, et al. (1986)), exposure duration (Haahr & Andersen (2003); Shiri, et al. (2006); Silverstein, et al. (1987); Silverstein, et al. (1986); Violante, et al. (2007)), and posture (Haahr & Andersen (2003); LeManac'h, et al. (2011); Melchior, et al. (2006)) are risk factors for DUE MSDs. However, there are a few studies that suggest physical exposure has an uncertain relationship with DUE MSDs (Nathan, Keniston, Myers, & Meadows (1992); Trezius, et al. (1998)).

According to a report by Bernard (1997) there are several individual risk factors that need to be addressed when assessing influences on the development of WMSDs. The three most commonly mentioned individual risk factors appear to be age, gender, and BMI. There have been several studies that report age to be a major contributing factor to the development of MSDs (English, Maclaren, Court-Brown, Hughes, Porter, & Wallace, 1995; Fan, Silverstein, Bao, Bonauto, Howard, Spielholz, Smith, Polissar, & Viikari-Juntura, 2009; Ohlsson, Hansson, Balogh, Strömberg, Pålsson, Nordander, Rylander, & Skerfving, 1994) However, Bernard (1997) mentions that a survival bias may occur when analyzing the impact of age. Survivor bias happens when a worker develops a WMSD or some health problem and leaves their job to take a less strenuous job, thereby leaving only the workers who have not been negatively affected by their job (Bernard, 1997). Multiple studies report a higher prevalence of MSDs in women than in men (Bernard, Sauter, Fine, Petersen, & Hales, 1994; Chiang, Ko, Chen, Yu, Wu, & Chang, 1993; Fan, et al., 2009; Hales, Sauter, Peterson, Fine, Putz-Anderson, Schleifer, Ochs, & Bernard, 1994; Johansson, 1994; Stevens, Sun, Beard, O'Fallon, & Kurland, 1988). There has also been a lot of evidence that workers who are obese (BMI>29) tend to develop more WMSDs when compared to those who are slender (BMI<20) (Nathan, Keniston, Myers, & Meadows, 1992; Nathan, Keniston, Meadows, Lockwood, 1994; Nordstrom, Vierkant, DeStefano, & Layde, 1997; Vessey, Villard-Mackintosh, & Yeates, 1990; Werner, Albers, Franzblau, & Armstrong, 1994).

Job Analysis Methods

Commonly used job analysis methods for the DUE include the TLV for HAL, the SI, the Rapid Upper Limb Assessment (RULA), the State of Washington Checklist, and the Ergonomic Job Measurement System (EJMS). The most commonly used models in research studies appear to be the TLV for HAL and the SI, which is the reason they are investigated in this study. The other methods have had limited investigation into their effectiveness as risk prediction models and is why they are not discussed in this study.

Strain Index. The SI is an assessment method for identifying those jobs that are unsafe and likely associated with DUE MSDs and those jobs that are not (Moore and Garg, 1995). The SI relies on the measurement or estimation of six semi-quantitative task variables that describe the physical stress of a job based on physiological and biomechanical theories of the DUE and epidemiological findings (Garg & Kapellusch, 2011). The six task variables used in the SI are: (i) intensity of exertion (applied force), (ii) number of exertions per minute, (iii) percent duration of exertion per cycle, (iv) hand/wrist posture, (v) speed of work, and (vi) duration of exposure per day. Each of these categories has five rating values that are used to describe the physical exposure. Multipliers correspond to the task variable ratings, which act as penalties. The multipliers are used to compute a multiplicative score, which is the Strain Index Score. (Moore & Garg, 1995)

A study by Moore, et al., (2001) analyzed the performance of the SI and compared it to several risk factors. Several generic risk factors were included in the analysis (i.e. high forcefulness, high repetitiveness, pinch grasp, gloves, non-neutral posture, vibration, localized compression, cold, etc.). The authors found that the odds ratio for the SI was 108.3 (CI = 16.7, 705.0) and was 3 to 16 times larger than any other factors studied. The SI force rating alone offered the next highest odds ratio of 36.0 (CI = 4.3, 303.4), followed by the combination of SI force rating combined with high repetitiveness with an odds ratio of 31.2 (CI = 3.7, 262.1). The authors found that the SI performed better than any of the individual or combinations of generic risk factors and that it's sensitivity, specificity, positive predictive value, and negative predictive value were all approximately 0.90. These results provide evidence of the SI's external and predictive validity.

Another study by Rucker and Moore, 2002 analyzed predictive validity of the SI in two manufacturing plants. Investigators, who were blinded to health outcomes, analyzed the right and left sides of 28 jobs using the SI and classified them as "hazardous" or "safe". The occurrence of DUE MSDs were determined using OSHA 200 logs. When the authors compared sides, symmetry between morbidity and hazard classification was required. When comparing jobs, this symmetry was not required. 2 x 2 contingency tables were used to determine an association between the hazard classifications and the morbidity classifications for the 56 sides and 28 jobs. For the sides, the authors found a significant association between hazard classification and morbidity classification with an empirical odds ratio of 73.2. The sensitivity, specificity, positive predictive value, and negative predictive value were 1.00, 0.84, 0.47, and 1.00, respectively. In addition, a similar association was found with jobs, with an empirical odds ratio of 106.6, and the sensitivity, specificity, positive predictive value, and negative predicative value of 1.00, 0.91, 0.75, and 1.00, respectively. These results demonstrate that the SI is able to identify tasks that place workers at increased risk of DUE MSDs. They also demonstrate the SI's external validity.

Knox & Moore (2001) analyzed the predictive validity of the SI in turkey processing. Investigators, who were blinded to health outcomes, analyzed the right and left sides of workers in 28 jobs using the SI and classified them as “hazardous” or “safe,” based on the SI score. OSHA 200 logs were used to determine the occurrence of DUE MSDs. 2 x 2 contingency tables were used to find an association between the hazard classifications and the morbidity classifications for the 56 right and left hands and the 28 jobs. For the sides, the authors found, the association between hazard classification and morbidity classification to be statistically significant (OR = 22.0, $p < 0.001$). The sensitivity, specificity, positive predictive value, and negative predictive value were 0.86, 0.79, 0.92, and 0.65, respectively. The authors noted similar results for the jobs (OR = 50.0, $p = 0.001$). The sensitivity, specificity, positive predictive value, and negative predictive value were 0.91, 0.83, 0.95, and 0.71. These results provide additional evidence of the external validity and predictive validity of the SI. These results demonstrate that the SI can effectively identify tasks that do and do not place workers at an increased risk of DUE MSDs. These results also demonstrate the SI’s external validity.

Stephens, Vos, Stevens, & Moore, 2006, evaluated the test-retest repeatability of published data collection and rating methods of the SI by analyzing 61 job video files twice over a 5-month period. The authors found intraclass correlation coefficients for task variable ratings and accompanying data ranged from 0.66 to 0.95 for both individuals and teams. The authors also found SI Score intraclass correlation coefficients for individuals and teams were 0.56 and 0.82, respectively. Intra-rater reliability for the hazard classification was 0.81 for individuals and 0.88 for teams. These results suggest a good test-retest repeatability for the SI.

TLV for HAL. TLV for HAL is based on two variables, which are hand activity and normalized peak hand force. Hand activity level (HAL) is represented as a numerical score (0-10) and can be either referenced from a table based on frequency of exertion (efforts per minute) and duty cycle (percent duration of exertion), or from a verbal anchor scale (Latko, Armstrong, Foulke, Herrin, Rabourn, & Ulin, 1997). Normalized peak hand force (NPF) can be calculated by using EMG, or estimated using the Borg CR-10 rating, and is expressed on a 0-10 scale. Two limits are defined with TLV for HAL, using peak force and HAL rating; they are the action limit (AL) and the threshold limit value (TLV) (American Council of Governmental Industrial Hygensists, 2002). HAL and peak force are plotted on the TLV for HAL evaluation graph. If the job falls above the TLV line on the graph, it is said to be hazardous to most workers. If the plotted point falls below the AL line, the job is said to be “safe” to most workers. Jobs falling between the TLV and AL line are at moderate risk. The TLV for HAL is only intended to be used for “mono-task jobs”, where similar motions are performed repeatedly for four or more hours a day.

A cross-sectional study by Franzblau, Armstrong, Werner, and Ulin (2005) used 908 workers from multiple job sites to analyze prevalence of symptoms and upper extremity disorders with the TLV for HAL. The authors categorized workers exposures as above the TLV, above the AL but below the TLV, or below the AL. The authors found that all measures of CTS ($X^2 = 4.34$, $p = 0.037$) and elbow and forearm tendonitis ($X^2 = 11.68$, $p = 0.0006$) were significantly associated with TLV category. The authors found that symptoms in the DUE and wrist, hand, and finger tendonitis did not vary by TLV category. The authors note that some symptoms and specific disorders occurred below the AL, indicating that even with “acceptable” levels of hand activity, workers may develop symptoms and/or disorders. These results suggest limited support for the effectiveness and validity of the TLV for HAL. However, the authors found TLV categories were positively associated with both elbow/forearm tendinitis and diagnosed CTS.

Bonfiglioli, Mattioli, Armstrong, Graziosi, Marinelli, Farioli, & Violante (2012) evaluated the risk of CTS using the TLV for HAL. There were 3,860 participants who had completed all baseline criteria. The authors found that the TLV classification predicted both CTS symptoms (IRR between AL and TLV 2.43, 95% CI = 1.77 – 3.33; IRR above TLV 3.32, 95% CI = 2.34 – 4.72) and CTS confirmed by nerve conduction studies (IRR between AL and TLV 1.95, 95% CI = 1.21 – 3.16; above TLV 2.70, 95% CI = 1.48 – 4.91). These results demonstrate support for the effectiveness of the TLV for HAL when analyzing CTS.

In addition to studies looking solely at the SI or the TLV for HAL, there have been a few studies that analyze both. A study by Spielholz, Bao, Howard, Silverstein, Fan, Smith, & Salazar (2008) evaluated both job analysis methods using 567 participants from 12 companies in the manufacturing and health care industries. The authors performed inter-rater reliability comparisons on 125 selected cyclic tasks, with one novice and three experienced raters. HAL hand repetition ratings had a Spearman r value of 0.65 and a kappa value of 0.44 between raters. Subjective force estimates had a Spearman $r = 0.28$ and were not significantly different between raters ($p > 0.05$). The rating comparison for the four subjective components of the SI had Spearman r correlations of 0.37 – 0.62 and kappa values of 0.25 – 0.44. The SI and TLV for HAL agreed on exposure categorization 56% of the time. Logistic regression showed, after adjustment for age, gender, and BMI, that higher peak hand force estimates (OR = 1.14, 95% CI = 1.02 – 1.27), most common force estimates (OR = 1.14, 95% CI = 1.02 – 1.28), hand/wrist posture rating (OR = 1.71, 95% CI = 1.15 – 2.56), SI scores ≥ 7 compared with ≤ 3 (OR = 2.33, 95% CI = 1.20 – 4.53), and SI scores ≥ 7 compared with < 7 (OR = 1.82, 95% CI = 1.04 – 3.18) were associated with distal upper extremity disorders in the dominant hand. HAL repetition ratings ≥ 4 (OR = 2.81, 95% CI = 1.40 – 5.62) and hand/wrist posture ratings (OR = 1.59, 95% CI = 1.01 – 2.49) were associated with disorders in the nondominant hand. Therefore, these results show moderate to good inter-rater agreement and significant relationships to health outcomes.

Another study by Garg, Kapellusch, Hegmann, Wertsch, Merryweather, Deckow-Schaefer, Malloy, & the WISTAH Hand Study Research Team (2012) analyzed both the SI's and TLV for HAL's ability to predict risk of developing CTS. The authors used a cohort of 536 workers from 10 manufacturing facilities. The workers were followed monthly for six years. The authors found multiple factors that predict the development of CTS, which include: job physical exposure (measured by TLV for HAL and the SI), age, BMI, other MSDs, inflammatory arthritis, gardening outside or work and feelings of depression. In the adjusted models, the TLV for HAL and the SI were both significant per unit increase in exposure with hazard ratios (HR) increasing up to a maximum of 5.4 ($p = 0.05$) and 5.3 ($p = 0.03$), respectively; however, both suggested relatively lower risk at higher exposures. The results from this study suggest that the TLV for HAL and the SI are useful ways of estimating exposure to physical exposure risk factors.

The results from the existing literature regarding the SI and the TLV for HAL show that both have been shown to be somewhat reliable and valid. When analyzing the literature, the TLV for HAL seems to be less proven than the SI. One reason for this may be that the TLV for HAL has not been studied as thoroughly as the SI. However, both seem to demonstrate good external validity and high sensitivity and specificity.

Methods

Description of Data Obtained for Current Research (Parent Study)

Brief Description of Parent Study. The parent study was a longitudinal study of 1,205 volunteer workers from 21 manufacturing companies located in IL, UT, and WI. These workers perform various activities including: poultry processing, manufacturing and assembly, small electric motor manufacturing and assembly, metal automotive engine parts manufacturing, and plastic and rubber automotive engine parts manufacturing and assembly. Workers participated in the study for up to 6 years. Physical exposure and health outcomes data were quantified at baseline, and re-assessed at regular intervals throughout the study.

Baseline Health Data – Description. Data were collected through a questionnaire, structured interview, physical examination, and a nerve conduction study (NCS). A trained occupational therapist administered the questionnaire and the structured interview. The questionnaire included demographic, individual, and psychosocial data. The structured interview assessed the presence of symptoms of numbness/tingling and/or pain in the distal upper extremity (DUE). In addition, the baseline structured interview included assessment of the history of specific disorders and treatments (e.g. CTS, CTS release, etc.). Symptoms and history of disorders were recorded for each hand separately. A comprehensive physical exam was performed on each participant by the same therapist that conducted the structured interview. During the physical examination of the neck to hand regions, the therapist conducted palpation, performed physical maneuvers, and measured height and weight to calculate body mass index (BMI). A second, confirmatory physical exam was administered by an occupational medicine physician. Regardless of symptoms, all workers underwent a nerve conduction study (NCS) of each hand at baseline. These were conducted by a board certified physiatrist who was blinded to the workers' symptoms and job physical exposures. The physiatrist classified workers as having a "normal" NCS, or an "abnormal" NCS, consistent with median mononeuropathy at the wrist (a detailed health outcomes methodology is available in Garg, Kapellusch, Hegmann, & Merryweather, 2010).

Baseline Job Data – Description. Job physical exposure data were assessed for each hand separately on a per worker basis by trained ergonomic analysts. Job data were obtained through interviews with the workers and their supervisors, by observation, by measurement, and by video analysis. Numerous job physical exposure data were collected including: (i) estimated hand forces (Borg CR-10 scale, Borg 1982), (ii) number of exertions per minute, (iii) duration of hand exertions per cycle and length of work shift, (iv) hand/wrist posture, (v) speed of work, and (vi) duration of exposure per day. Analyst overall force rating, frequency and duration of exertions, Hand Activity Level (HAL) rating, hand/wrist postures, and speed of work were measured using a verbal anchor scale (Latko, 1997; American Council of Governmental Industrial Hygenists, 2002). See Appendix A for specific job data forms used to collect baseline job data.

Follow-up Assessment of UED Health – Description. A trained occupational therapist visited each worker each month to monitor existing symptoms and to determine if new symptoms developed during the preceding month. This was done through a structured interview at the participant's work station. If the participant experienced new/changed symptoms, a new, partial physical exam was completed by the therapist. Every six months, those workers who had symptoms consistent with CTS received a follow-up NCS.

Follow-up Job Data. Every quarter a trained ergonomics analyst, visited workers at their workstations to determine if the worker was performing the same job or if he/she was assigned to a new or different job. If the worker was determined to have a job change, the analyst studied the new job in the same manner as they did at baseline.

Methodology of Current Research

Determination of Study Cohort. Subjects for this study were drawn from the 1,205 workers who participated in the above described parent study. The health outcome of interest was incidence of aggregate DUE MSDs, defined as: (i) CTS, (ii) lateral epicondylitis, (iii) medial epicondylitis, (iv) hand/wrist tendonitis, (v) de Quervain's disease, and/or (vi) trigger finger. Incidence of aggregate disorders were compared to physical exposure quantified using the SI and TLV for HAL. The unit of analyses was the individual worker and analyses were performed at the "person-level". That is, a health outcome could occur in the left, right, or both arms, and physical exposure was the greater of left/right. Eligible workers were those who: (i) underwent complete health baseline measurement, (ii) underwent complete job baseline measurement, (iii) had quantified job physical exposure quantified (i.e. video analysis), and (iv) received one or more monthly follow-up measurements. Those workers who met a specific DUE MSD case definition for an aggregate disorder at baseline, who previously had an aggregate

DUE MSD, or who were ineligible to become a case for one or more aggregate DUE MSDs were excluded. Those persons reporting symptoms due to an acute injury (e.g. accident) were excluded by censoring them as a non-event one day before reporting the symptoms.

Computation of 'Job Metrics' at the Task and Job Levels. For this study, workers were considered to be performing one job at a time. Workers could change jobs throughout the study, triggering a job re-assessment. Each job consisted of one or more tasks (e.g. machine operator, assembly worker, etc.) and each task consisted of one or more sub-tasks (e.g. install screws, paint parts; see Figure 1).

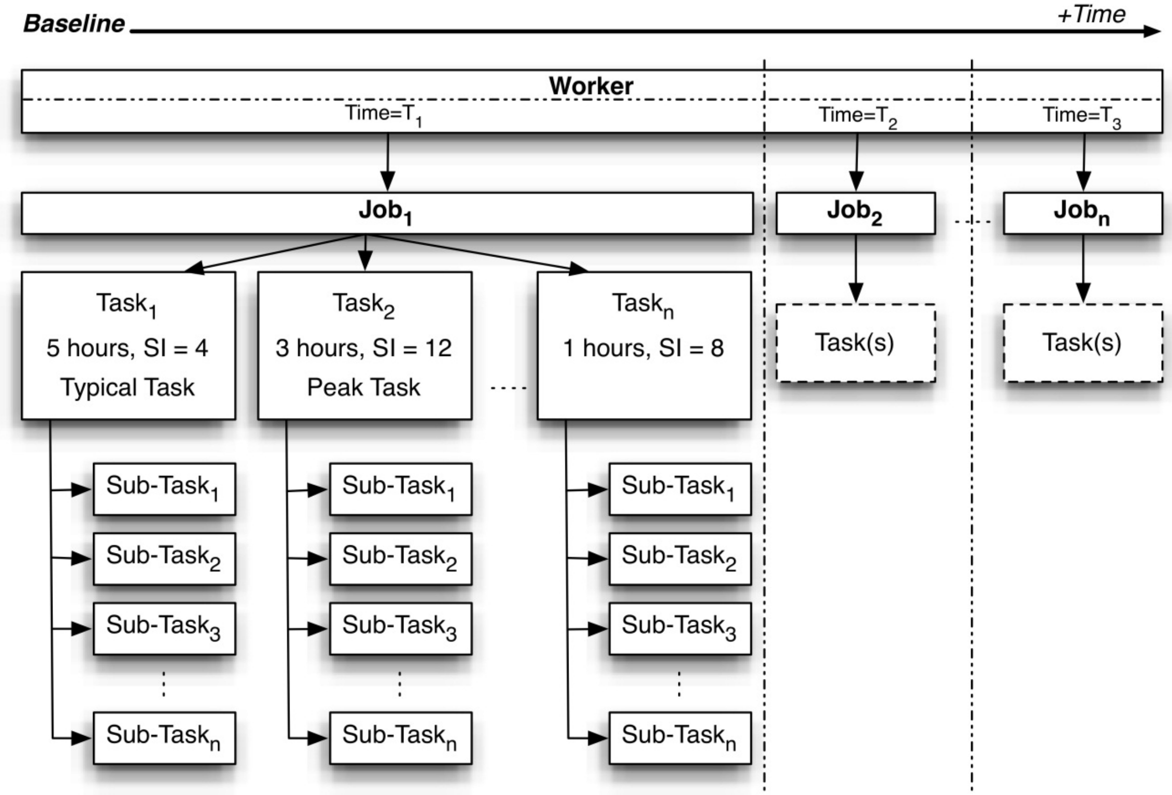

Figure 1. Example of how the breakdown of job, tasks, and subtasks occurred for each worker.

Determining Scores for the Strain Index and TLV for HAL. SI assessments of sub-tasks were performed using frame by frame video analysis based to the SI methodology (Moore and Garg, 1995). Analysts estimated force rating (Borg CR-10), number of efforts/min, duty cycle of efforts (% duration of exertion), hand/wrist posture, and speed of work were recorded. SI sub-task ratings were summarized at the task level using the following protocol. Overall intensity of exertion was determined using an algorithm developed by Drs. Garg and Kapellusch (Appendix B). The algorithm rating of force, as well as the analyst rating of overall force were used to determine amount of intensity of exertion. Total efforts per minute and total duty cycle were determined by summing all sub-task measurements. Hand/wrist posture and speed for the task were defined as those occurring most often during sub-tasks (by percentage of time).

TLV for HAL score was defined as [analyst Peak Force Rating on Borg CR-10 scale ÷ (10 – HAL Rating)]. Analyst Peak Force rating was measured from sub-tasks. HAL Rating was estimated using the HAL verbal anchor scale and the rating was provided at the task-level.

For this study, two methods were used to quantify physical exposure at the worker level for complex jobs (i.e. jobs with two or more tasks): (i) peak exposure, and (ii) typical exposure. Peak exposure referred to the task with the highest score (TLV for HAL and SI separately). Typical exposure referred to the job performed for the greatest percentage of time. In the event that two tasks shared typical exposure (e.g. a tie in duration), the task with higher physical exposure was chosen.

Occupational UED Health Outcomes – Case Definitions. A worker could have an aggregate disorder either in the left, right or both hands for the person level analyses used in this research. Those workers meeting the case definition at baseline, or who had previously been diagnosed as having an aggregate disorder were excluded from eligibility for becoming an incident case.

Specific case definitions were used to diagnose aggregate disorders. These case definitions remained the same throughout the study and reflect the case definitions used in the parent study's technical report (Garg, et. al, 2010). Specific case definitions are provided in Table 1. Workers were considered a "case" upon meeting the criteria for one or more specific case definitions. Workers reporting that they received medical treatment (e.g. injection, surgery) for one or more aggregate DUE MSDs became an incident case at the time they received treatment. Workers who developed symptoms of a specific DUE MSD due to an accident or an acute injury (e.g. fall, laceration) were right censored (and recorded as a non-case) one day prior to the accident.

Table 1: Specific case definitions for aggregate disorders

Disorder	Symptoms	Maneuver/ Measurement	Exclusions & Right Censor Conditions
CTS	1. Numbness/tingling in 2 or more median nerve served digits (1-4) for at least 2 consecutive monthly follow-up interviews plus abnormal NCS	- Abnormal NCS (time difference between +NCS and consecutive N/T follow-ups ≤ 6 months)	- Evidence of systemic neuropathy - Prior diagnosis of CTS by a Physician -History of a carpal tunnel release - Amputation of second or third digit at MCP or PIP in either hand
Lateral Epicondylitis	1. Lateral elbow pain for ≥ 50% days on monthly follow-up interview	- Pain upon palpation of 1 or more of 6 lateral tender points (from monthly follow-up physical exam) - Positive resisted wrist extension (this test is positive if it elicits pain over the lateral epicondyle)	- Prior diagnosis of lateral epicondylitis - Prior elbow surgery of unknown type and/or injection - Prior radial nerve pain
Medial Epicondylitis	1. Medial elbow pain for ≥ 50 percent days on monthly follow-up interview	- Pain upon palpation of 1 or more of 2 medial tender points (from monthly follow-up physical exam) - Positive resisted wrist flexion (this test is positive if it elicits pain over the medial epicondyle)	- Prior diagnosis of medial epicondylitis - Prior elbow surgery of unknown type and/or injection - Prior ulnar neuropathy or cubital tunnel surgery, OR clinical impression of ulnar neuropathy

Table 1 (cont.): Specific case definitions for aggregate disorders cont.

Extensor Tendonitis	1. Dorsal wrist pain for ≥ 50% days on monthly follow-up interview 2. 2-6 extensor compartment tenderness (dorsal wrist area)	- Positive resisted wrist extension (this test is positive if it elicits pain over the lateral epicondyle)	- History of wrist arthritis - Prior diagnosis of extensor tendonitis - Prior surgery for extensor tendinitis - Prior wrist surgery or injection of unknown type Right Censored: - Develops wrist arthritis
Flexor Tendonitis	1. Volar wrist pain for ≥ 50% days on monthly follow-up interview 2. No numbness/tingling in digits 1-4 from monthly follow-up interview	- Three locations of digital flexor tendon tenderness from monthly follow-up physical exam - Positive resisted wrist flexion (this test is positive if it elicits pain)	- Prior diagnosis of flexor tendonitis - Prior surgery for flexor or extensor tendinitis - Prior wrist surgery or injection of unknown type - History of wrist arthritis Right Censored: - Develops wrist arthritis
De Quervain's Disease	1. Radial wrist pain (thumb side) for ≥ 50 % days on monthly follow-up interview	- 1st extensor compartment tenderness (base of thumb) from monthly follow-up physical exam - Positive Finkelstein test (active) from monthly follow-up physical exam	- Prior deQuervain's diagnosis - Prior deQuervain's surgery - Hand surgery or injection of unknown origin - History of CMC/Wrist/MCP arthritis Right Censored: - Develops CMC/Wrist/MCP arthritis
Trigger Finger	1. Pain in the finger from monthly follow-up interview and focal tenderness over A-1 pulley (close to the MCP joint) from physical exam	- Demonstrated triggering (a catching of a digital flexor tendon as it glides under the A-1 pulley) from monthly follow-up physical exam OR monthly interview	- History of trigger finger/thumb - Prior finger/hand surgery - MCP/finger osteoarthritis at baseline

Statistical Analyses

Statistical Modeling. Typical exposure was used for analysis, since this is the exposure the worker experiences the most. Time to first event of aggregate disorders was modeled using proportion hazards (PH) regression (Cox, 1972). Incident cases were censored from the timeline on the day they met the case definition for one or more aggregate disorders. Workers, who left the study prior to becoming an incident case, were censored at the time they left the study (and were non-cases).

Since physical exposure could change throughout the study, the SI and TLV for HAL were treated as time-varying covariates within the model. Age, gender, and BMI were treated as time-independent variables using baseline values.

Separate models were created for SI and TLV for HAL using both their continuous forms and pre-defined categories as reported in Moore, Vos, Stephens, & Garg (2006) for SI, American Council of Governmental Industrial Hygienists (2002) for TLV for HAL. Age, gender, and BMI were used as covariates in both models. All statistical analyses were performed in R-64 version 2.13.1 (R Development Core Team, 2011).

Determining Functional Form of Continuous Variables. The function form of the SI, TLV for HAL, age, and BMI were determined by fitting the null PH model of aggregate disorders and plotting the Martingale Residuals of that model against each variable separately. (Therneau, Grambsch, & Fleming, 1990) Cubic spline smoothing curves were used to display the functional form of the variables.

The variables showing a linear relationship between the variable and incident cases, were modeled as linear functions. The variables suggesting a non-linear relationship, were transformed using linear splines with a single knot. The knot of the linear spline was placed at the nearest quantile of cases to the inflection point on the function form.

Results

Descriptive Statistics

Enrollment. Workers were recruited during the first 18 months from the beginning of the study. Out of 673 workers initially enrolled at baseline, 552 workers (82%) completed job baseline data collection and 667 (99%) completed the health baseline data collection (Figure 2). A total of 552 (82%) workers completed both job and health baseline data collections and of these 536 (97%) completed one or more months of follow-up. Of these workers, 264 (49%) were eligible to participate in the study and 272 (51%) were ineligible to participate. Over the six-year follow-up period, 69 of the 264 workers became incident cases (26%).

Prevalence. Point and lifetime prevalence for each of the six aggregate DUE MSDs within the cohort of 536 workers were calculated and are provided in Table 2. For CTS, baseline prevalence was 10% and life prevalence was 20%. Point prevalence for lateral epicondylitis was 5% and life prevalence was 15%. For medial epicondylitis, point prevalence was 1% and life prevalence was 4%. Point prevalence for de Quervain’s disease is 5% (25 cases: 1 male, 24 females) and lifetime prevalence is 5% (28 cases: 1 male, 27 females). For trigger finger, point prevalence is 12% (63 cases: 12 males, 51 females) and life prevalence is 25% (132 cases: 38 males, 94 females). Point prevalence for extensor tendinitis was 9% and 1% for flexor tendinitis. Life prevalence for both flexor and extensor tendinitis was 18% (94 cases: 19 males, 75 females).

Table 2: Point and lifetime prevalence for the six aggregate DUE MSDs

Specific Aggregate Disorders	Point Prevalence	Lifetime Prevalence
CTS	55/10%	106/20%
Lateral Epicondylitis	28/5%	82/15%
Medial Epicondylitis	6/1%	22/4%
Extensor Tendonitis **Flexor Tendonitis**	Extensor Tendonitis: 47/9% Flexor Tendonitis: 6/1%	94/18%
DeQuervain's Disease	25/5%	28/5%
Trigger Finger	63/12%	132/25%

Number of cases/Percentage of cases out of entire cohort (N = 536)

Occurrence of Aggregate Disorders. Among the 69 workers who became incident cases, 24 (35%) developed two disorders and three (4%) developed three disorders. Lateral epicondylitis was the first disorder to occur in 19 (28%) cases, followed closely by trigger finger, which occurred first in 17 (25%) cases and CTS, which occurred first in 12 (17%) cases (Table 3). Trigger finger was the second disorder among 8 of the 24 (33%) workers who developed two or more disorders. All other second disorders occurred about equally. Among the incident cases, trigger finger and lateral epicondyltiis most commonly occurred with 25 of 69 (36%) and 23 of 69 (33%) of workers developing these disorders respectively. CTS occurred in 15 of 69 workers (22%). The remaining disorders occurred in 10 of 69 (14%) of workers or less each.

Table 3: Order of occurrence for specific aggregate disorders

Disorders	Number of Cases that Developed as the First Disorder	Number of Cases that Developed as a Second Disorder	Number of Cases that Developed as a Third Disorder	Total Occurrences
CTS	12	3	0	15
Lateral Epicondylitis	19	3	1	23
Medial Epicondylitis	6	3	0	9
Trigger Finger	17	8	0	25
DeQuervain's	6	2	2	10
Extensor Tendinitis	6	3	0	9
Flexor Tendinitis	3	2	0	5

Covariates. Demographics of the total cohort, virgin cohort (incident eligible) and prevalent cohort (not incident eligible) are provided in Table 4. The mean age of the total participants was 42.16 (eligible 39.67, ineligible 44.57). The mean BMI for total participants is 29.09 (eligible 28.27, ineligible 29.90). Of the total cohort, 361 (67.4%) are female and 175 (32.6%) are male (eligible females = 155 (58.7%), males = 109 (41.3%), ineligible females = 206 (75.7%), males = 66 (24.3%)).

Table 4: Descriptive statistics for covariates

Variable	Category	n	Percentage or Mean ± Standard Deviation (range)
Age at baseline			
Age (total)	Continuous	536	42.16 ± 11.55 (18.7 – 68.1)
Eligible	Continuous	264	39.67 ± 11.95 (18.7 – 68.1)
Ineligible	Continuous	272	44.57 ± 10.64 (19.3 – 68)
BMI at baseline			
BMI (total)	Continuous	536	29.09 ± 6.81 (16.5 – 58.6)
Eligible	Continuous	264	28.27 ± 6.16 (16.5 – 54.9)
Ineligible	Continuous	272	29.9 ± 7.31 (16.6 – 58.6)
Gender (total)	Female	361	67.4%
	Male	175	32.6%
Eligible	Female	155	58.7%
	Male	109	41.3%
Ineligible	Female	206	75.7%
	Male	66	24.3%

Physical Exposure Variables. Descriptive statistics physical exposure variables are provided in Table 5. The mean intensity rating for the analyst SI for the entire cohort is 2.37 ± 0.88 (0.5 - 5) (eligible M = 2.33 ± 0.82 (0.5 – 5), ineligible M = 2.41 ± 0.94 (0.5 – 5)). The mean intensity rating from the algorithm SI for the entire cohort is 2.49 ± 1.18 (0.5 – 10) (eligible M = 2.51 ± 1.1 (0.5 – 7), ineligible M = 2.48 ± 1.25 (0.5 – 10)). The mean score for the algorithm SI with the entire cohort is 17.3 ± 19.36 (0.75 – 234) (eligible M = 16.41 ± 14.41 (0.75 – 81), ineligible M = 18.16 ± 23.16 (0.75 – 234)). The mean SI intensity score for the entire cohort is 15.26 ± 13.83 (0.75 – 108) (eligible M = 14.42 ± 13.21 (0.75 – 108), ineligible M = 16.08 ± 14.38 (0.75 – 108)).

The mean analyst TLV rating for the entire cohort is 0.87 ± 0.62 (0.07 – 6) (eligible M = 0.83 ± 0.59 (0.1 – 6), ineligible M = 0.90 ± 0.64 (0.07 – 4)). The mean worker TLV rating for the entire cohort is 1.04 ± 0.84 (0 - 7) (eligible M = 0.98 ± 0.74 (0.13 – 5), ineligible M = 1.09 ± 0.93 (0 – 7)). Additionally, the mean efforts per minute for the entire cohort is 26.19 ± 14.53 (0.8 – 98.3) (eligible M = 26.49 ± 15.2 (1.6 – 98.3), ineligible M = 25.90 ± 13.87 (0.8 – 69)).

Table 5: Descriptive statistics for physical exposure factors

Variable	**Category**	**n**	**Percentage or Mean ± Standard Deviation (range)**
Analyst SI – Intensity (Typical)	Continuous	536	2.37 ± 0.88 (0.5 – 5)
Eligible	Continuous	264	2.33 ± 0.82 (0.5 – 5)
Ineligible	Continuous	272	2.41 ± 0.94 (0.5 – 5)
Algorithm SI – Intensity (Typical)	Continuous	536	2.49 ± 1.18 (0.5 – 10)
Eligible	Continuous	264	2.51 ± 1.1 (0.5 – 7)
Ineligible	Continuous	272	2.48 ± 1.25 (0.5 – 10)
Algorithm SI – Score (Typical)	Continuous	536	17.3 ± 19.36 (0.75 – 234)
Eligible	Continuous	264	16.41 ± 14.41 (0.75 – 81)
Ineligible	Continuous	272	18.16 ± 23.16 (0.75 – 234)
SI Intensity – Score (Typical)	Continuous	536	15.26 ± 13.83 (0.75 – 108)
Eligible	Continuous	264	14.42 ± 13.21 (0.75 – 108)
Ineligible	Continuous	272	16.08 ± 14.38 (0.75 – 108)
Analyst TLV (Typical)	Continuous	536	0.87 ± 0.62 (0.07 – 6)
Eligible	Continuous	264	0.83 ± 0.59 (0.1 – 6)
Ineligible	Continuous	272	0.9 ± 0.64 (0.07 – 4)

Table 5 (cont.): Descriptive statistics for physical exposure factors

Variable	Category	n	Percentage or Mean ± Standard Deviation (range)
Worker TLV (Typical)	Continuous	536	1.04 ± 0.84 (0 – 7)
Eligible	Continuous	264	0.98 ± 0.74 (0.13 – 5)
Ineligible	Continuous	272	1.09 ± 0.93 (0 – 7)
SI Efforts Per Minute (Typical)	Continuous	536	26.19 ± 14.53 (0.8 – 98.3)
Eligible	Continuous	264	26.49 ± 15.2 (1.6 – 98.3)
Ineligible	Continuous	272	25.9 ± 13.87 (0.8 – 69)

Group Differences. Chi-square and independent samples t-tests were run to determine significant differences among eligible and ineligible participants. The workers of the virgin cohort were proportionally more male than female (41.3% male in eligible vs. 24.3% male in ineligible, $X^2 = 17.66$, $p \leq 0.001$) and had lower BMI eligible = 28.26, ineligible = 29.90, $p = 0.01$). No significant differences were found between eligible and ineligible workers for age, worker TLV, algorithm SI – intensity, analyst SI – intensity, algorithm SI score, SI intensity score, and efforts per minute.

Univariate Analyses

Table 6 summarizes the results from univariate analyses of the age, gender, and BMI covariates. Age (HR = 1.03 (95% CI: 1.01 – 1.05), $p = 0.001$) and gender (HR = 2.38 (95% CI: 1.36 – 4.17, $p = 0.002$) were found to be statistically associated with increased risk of aggregate upper extremity disorder. No increased risk was associated with BMI (HR = 1.02, 95% CI: 0.99 – 1.06, $p = 0.22$).

Table 6: Univariate hazard ratios for covariates

Variable (overall *p*-value)	**Categories**	**N (eligible)**	**HR (95% CI)**	***p*-value**
Age	Continuous-linear (per unit increase)	264 (69)	1.03 (1.01 – 1.05)	0.001**
BMI	Continuous-linear (per unit increase)	264 (69)	1.02 (0.99 – 1.06)	0.216
Gender	Male	109 (16)	1.00	
	Female	155 (53)	2.38 (1.36 – 4.17)	0.002**

** statistically significant difference ($p \leq 0.01$)

No statistically significant association with increased risk for aggregate DUE MSDs was found for TLV for HAL or the SI ($p > 0.13$) (Table 7). Secondary analyses found that when transformed using a linear spline, efforts per minute was associated with increased risk of aggregate disorders ($p < 0.03$) (Table 7).

Table 7: Univariate hazard ratios for exposure variables

Variable	**Category/function**	***N* (cases)**	**Hazard Ratio[2]**	**95% CI**	***p*-value**
Analyst SI Model	*Linear*	264 (69)	1.01	0.99 – 1.03	0.22
	Linear Spline (p=0.43)[1]				
	Per unit increase ≤ 9	141 (37)	1.04	0.93 – 1.17	0.46
	Per unit increase > 9	123 (32)	0.97	0.86 – 1.09	0.58[3]
	Categorical				
	≤ 6.1	78 (17)	1.00		
	> 6.1	186 (52)	1.53	0.88 – 2.65	0.13
Algorithm SI Model	*Linear*	264 (69)	1.00	0.99 – 1.02	0.81
	Linear Spline (p=0.96)[1]				
	Per unit increase ≤ 9	133 (38)	1.01	0.91 – 1.23	0.83
	Per unit increase > 9	131 (31)	0.99	0.88 – 1.11	0.86[3]
	Categorical				
	≤ 6.1	63 (18)	1.00		
	> 6.1	201 (51)	0.96	0.56 – 1.64	0.88

[1] Overall p-value for variable transformed as linear spline.

[2] Hazard Ratio of 1.0 with no confidence interval indicates reference category for the variable.

[3] This p-value is for the second spline term and represents a test for change in slope at the knot. Thus, this p-value does not correspond to the given confidence interval, which is for the HR beyond the knot point.

Table 7 (cont.): Univariate hazard ratios for exposure variables

Variable	**Category/function**	***N* (cases)**	**Hazard Ratio[2]**	**95% CI**	***p*-value**
Analyst TLV for HAL	*Linear*	264 (69)	1.08	0.78 – 1.50	0.64
	Linear Spline (p=0.81)[1]				
	Per unit increase ≤ 0.75	199 (41)	0.75	0.15 – 3.70	0.72
	Per unit increase > 0.75	65 (28)	1.50	0.27 – 8.35	0.64[3]
	Categorical				
	< AL	61 (17)	1.00		
	AL ≤ score ≤ 0.78	99 (24)	0.75	0.40 – 1.39	0.36
	> TLV	104 (28)	1.09	0.59 – 2.00	0.78
Efforts per Minute	*Linear*	264 (69)	1.01	0.99 – 1.03	0.09
	Linear Spline (p=0.02)[1]				
	Per unit increase ≤ 37.3	211 (52)	1.04	1.01 – 1.07	0.005
	Per unit increase > 37.3	53 (17)	0.94	0.88 – 0.99	0.03[3]
SI Force Analyst Rating	*Linear*	264 (69)	0.97	0.73 – 1.29	0.85
	Linear Spline (p=0.61)[1]				
	Per unit increase ≤ 3	246 (64)	0.87	0.61 – 1.24	0.45
	Per unit increase > 3	18 (5)	1.68	0.61 – 4.63	0.32[2]
SI Force Algorithm Rating	*Linear*	264 (69)	0.83	0.67 – 1.04	0.11
	Linear Spline (p=0.25)[1]				
	Per unit increase ≤ 3	220 (61)	0.86	0.63 – 1.18	0.35
	Per unit increase > 3	44 (8)	0.91	0.44 – 1.88	0.79[3]

[1] Overall p-value for variable transformed as linear spline.
[2] Hazard Ratio of 1.0 with no confidence interval indicates reference category for the variable.
[3] This p-value is for the second spline term and represents a test for change in slope at the knot. Thus, this p-value does not correspond to the given confidence interval, which is for the HR beyond the knot point.

Multivariate Analyses

Cox Proportional Hazards Regression models were analyzed to determine if the SI was related to increased risk of developing an aggregate disorder after controlling for confounders. When introduced into the multivariate model of covariates, analyst SI, treated as a continuous variable, was not statistically associated with increased risk of aggregate disorder (p = 0.45). Analyst SI with two categories was also not statistically associated with increased risk (p = 0.50). When the algorithm SI was introduced into the multivariate model of covariates and treated as a continuous variable, it was determined to not be statistically associated with increased risk (p = 0.57). When algorithm SI was treated with two categories, it was also not determined to be significantly associated with increased risk (*p* = 0.55).

Cox Proportional Hazards Regression models were also analyzed to determine if TLV for HAL was associated with increased risk of developing an aggregate disorder. When introduced into the multivariate model of covariates analyst TLV for HAL, treated as a continuous variable, was not statistically associated with risk of aggregate disorder (*p* = 0.98). Analyst TLV for HAL, when treated with three categories, was also found to not be statistically associated with increased risk (*p* = 0.36).

When introduced into the multivariate model of covariates efforts per minute, treated as a continuous variable, was not statistically associated with increased risk of aggregate disorder (*p* = 0.40). Efforts per minute, when using a linear spline function (3rd quartile), approached significance (*p* = 0.07). See Tables 8-13 for detailed multivariate model information.

Table 8: Multivariate model for risk of aggregate disorders with analyst SI variable

Variable (overall *p*-value)[1]	**Category/function**	***N* (cases)**	**Hazard Ratio**	**95% CI**	***p*-value**
Analyst SI (*p*=0.45)[1]	Continuous (per unit increase)	264 (69)	1.01	0.99 – 1.03	0.44
Covariates					
Age (*p*=0.003)[1]	Continuous (per unit increase)	264 (69)	1.03	1.01 – 1.05	0.003
BMI (*p*=0.28)[1]	Continuous (per unit increase)	264 (69)	1.02	0.98 – 1.06	0.26
Gender (*p*=0.004)[1]	Male	109 (16)	1.00		
	Female	155 (53)	2.19	1.24 – 3.85	0.007

[1] Overall significance associated with including each variable in the model using the likelihood ratio test.

Table 9: Multivariate model for risk of aggregate disorders with analyst SI variable with 2 categories

Variable (overall *p*-value)[1]	**Category/function**	***N* (cases)**	**Hazard Ratio**	**95% CI**	***p*-value**
Analyst SI with 2 Categories (p=0.50)[1]	SI ≤ 6.1	78 (17)	1.00		
	SI > 6.1	186 (52)	1.21	0.69 – 2.15	0.51
Covariates					
Age (p=0.004)[1]	Continuous (per unit increase)	264 (69)	1.03	1.01 – 1.05	0.004
BMI (p=0.28)[1]	Continuous (per unit increase)	264 (69)	1.02	0.98 – 1.06	0.27
Gender (p=0.006)[1]	Male	109 (16)	1.00		
	Female	155 (53)	2.15	1.20 – 3.8	0.01

[1] Overall significance associated with including each variable in the model using the likelihood ratio test.

Table 10: Multivariate model for risk of aggregate disorders with algorithm SI variable

Variable (overall *p*-value)[1]	**Category/function**	***N* (cases)**	**Hazard Ratio**	**95% CI**	***p*-value**
Algorithm SI (p=0.57)[1]	Continuous (per unit increase)	264 (69)	1.01	0.99 – 1.02	0.56
Covariates					
Age (p=0.002)[1]	Continuous (per unit increase)	264 (69)	1.03	1.01 – 1.05	0.003
BMI (p=0.27)[1]	Continuous (per unit increase)	264 (69)	1.02	0.98 – 1.06	0.26
Gender (p=0.003)[1]	Male	109 (16)	2.24	1.28 – 3.93	0.005
	Female	155 (53)			

[1] Overall significance associated with including each variable in the model using the likelihood ratio test.

Table 11: Multivariate model for risk of aggregate disorders with algorithm SI variable with 2 categories

Variable (overall *p*-value)[1]	**Category/function**	***N* (cases)**	**Hazard Ratio**	**95% CI**	***p*-value**
Algorithm SI with 2 Categories (*p*=0.55)[1]	SI ≤ 6.1	63 (18)	1.00		
	SI > 6.1	201 (51)	0.84	0.48 – 1.47	0.55
Covariates					
Age (*p*=0.002)[1]	Continuous (per unit increase)	264 (69)	1.03	1.01 – 1.05	0.003
BMI (*p*=0.31)[1]	Continuous (per unit increase)	264 (69)	1.02	0.98 – 1.06	0.299
Gender (*p*=0.002)[1]	Male	109 (16)	1.00		
	Female	155 (53)	2.35	1.32 – 4.17	0.004

[1] Overall significance associated with including each variable in the model using the likelihood ratio test.

Table 12: Multivariate model for risk of aggregate disorders with analyst TLV for HAL variable

Variable (overall *p*-value)[1]	**Category/function**	***N* (cases)**	**Hazard Ratio**	**95% CI**	***p*-value**
Analyst TLV for HAL (*p*=0.98)[1]	Continuous (per unit increase)	264 (69)	0.995	0.70 – 1.41	0.98
Covariates					
Age (*p*=0.003)[1]	Continuous (per unit increase)	264 (69)	1.03	1.01 – 1.05	0.003
BMI (*p*=0.29)[1]	Continuous (per unit increase)	264 (69)	1.02	0.98 – 1.06	0.280
Gender (*p*=0.003)[1]	Male	109 (16)	1.00		
	Female	155 (53)	2.26	1.28 – 3.98	0.005

[1] Overall significance associated with including each variable in the model using the likelihood ratio test.

Table 13: Multivariate model for risk of aggregate disorders with analyst TLV for HAL with 3 categories

Variable (overall *p*-value)[1]	**Category/function**	***N* (eligible)**	**Hazard Ratio**	**95% CI**	***p*-value**
Analyst TLV for HAL with 3 Categories (*p*=0.36)[1]	< AL	61 (17)	1.00		
	AL ≤ score ≤ TLV	99 (24)	0.67	0.36 – 1.26	0.21
	> TLV	104 (28)	0.93	0.50 – 1.73	0.82
Covariates					
Age (*p*=0.004)[1]	Continuous (per unit increase)	264 (69)	1.03	1.01 – 1.05	0.004
BMI (*p*=0.27)[1]	Continuous (per unit increase)	264 (69)	1.02	0.98 – 1.06	0.260
Gender (*p*=0.002)[1]	Male	109 (16)	1.00		
	Female	155 (53)	2.34	1.32 – 4.13	0.003

[1] Overall significance associated with including each variable in the model using the likelihood ratio test.

Table 14: Multivariate model for risk of aggregate disorders with efforts per minute variable

Variable (overall *p*-value)[1]	**Category/function**	***N* (eligible)**	**Hazard Ratio**	**95% CI**	***p*-value**
Efforts per Minute (*p*=0.40)[1]	Continuous (per unit increase)	264 (69)	1.01	0.99 – 1.02	0.40
Covariates					
Age (*p*=0.003)[1]	Continuous (per unit increase)	264 (69)	1.03	1.01 – 1.05	0.003
BMI (*p*=0.28)[1]	Continuous (per unit increase)	264 (69)	1.02	0.98 – 1.06	0.26
Gender (*p*=0.008)[1]	Male	109 (16)	1.00		
	Female	155 (53)	2.11	1.18 – 3.78	0.01

[1] Overall significance associated with including each variable in the model using the likelihood ratio test.

Table 15: Multivariate model for risk of aggregate disorders with efforts per minute variable with spline

Variable (overall *p*-value)[1]	**Category/function**	***N* (cases)**	**Hazard Ratio**	**95% CI**	***p*-value**
Efforts per Minute with Linear Spline (*p*=0.07)[1]	*Spline terms*				
	Per unit increase ≤ 37.3	211 (52)	1.03	1.00 – 1.05	0.08
	Per unit increase > 37.3	53 (17)	0.95	0.89 – 1.01	0.12
Covariates					
Age (*p*=0.008)[1]	Continuous (per unit increase)	264 (69)	1.03	1.01 – 1.05	0.008
BMI (*p*=0.24)[1]	Continuous (per unit increase)	264 (69)	1.02	0.99 – 1.06	0.22
Gender (*p*=0.02)[1]	Male	109 (16)	1.00		
	Female	155 (53)	1.98	1.10 – 3.57	0.02

[1] Overall significance associated with including each variable in the model using the likelihood ratio test.

Discussion

The SI and the TLV for HAL have been shown to predict various DUE MSDs (Bonfiglioli, et al., 2012; Garg et al., 2012, Franzblau, et al., 2005; Gell, Werner, Franzblau, Ulin, & Armstrong, 2005; Werner, Ranzblau, Gell, Hartigart, Ebersole, & Armstrong, 2005; Moore, et al., 2006; Spielholz, et al., 2008; Violante, et al., 2007), but neither have been tested with a virgin cohort to predict the occurrence of a worker's first, aggregate, DUE MSD.

Associations between Physical Exposure and First Aggregate DUE MSD

Based on univariate analysis, this study suggests that the SI score may be associated with the development of aggregate DUE MSDs when using a high risk cut-point of 6.1 (Moore et al. 2006) for the SI score. (HR = 1.53, $p = 0.13$). This finding is similar to those of other studies that were able to detect an association between SI score and DUE MSDs and their symptoms (Garg, et al., 2012; Knox & Moore, 2001; Moore, et al. 2001; Rucker & Moore, 2002). No association was found between TLV for HAL and aggregate DUE MSDs. This finding is consistent with other studies that have failed to find an association between TLV for HAL category and DUE MSDs or their symptoms (Franzblau, et al. 2005, found that DUE symptoms were not associated with TLV category). Neither the SI, nor the TLV for HAL showed a relationship with occurrence of first aggregate DUE MSD when adjusted for age, gender and BMI.

Repetition is often mentioned as a contributor to work-related DUE MSDs (Haahr & Andersen, 2003; Shiri, et al., 2006; Thomsen, Hansson, Mikkelsen, & Lauritzen, 2002; van Rijn, Huisstede, Koes, & Burdorf, 2009). This study analyzed "efforts per minute," as a measure of repetition and found suggestive evidence of modestly increasing risk for first aggregate DUE MSD up to 37.3 efforts per minute (HR = 1.03 per unit increase, p = 0.08) when adjusting for age, gender and BMI.

Surprisingly, univariate analyses of intensity of exertion using a force algorithm revealed a modest protective effect (HR=0.83, 95% CI = 0.67 – 1.04, p=0.11) as intensity of exertion increased, though the effect was not statistically significant. This protective effect of force was unexpected and is contrary to previous studies that have suggested that increased force is a contributor to the development of DUE MSDs (Descatha, et al., 2003; Haahr & Andersen, 2003; Shiri, et al, 2006; Silverstein, et al., 1986; Silverstein, et al., 1987). Why force appears protective in this study remains unknown. One possible explanation is that higher forces are applied mostly on those tasks with low repetition, and lower forces are applied on mostly those tasks with higher repetition. If frequency of effort is more important than intensity of effort with regard to occurrence of first aggregate DUE MSD, then such a scenario would help to explain why: (i) increasing force appears protective, (ii) increasing frequency appears only modestly hazardous, (iii) SI score has a weak statistical relationship, and (iv) TLV for HAL shows no association. Such interactions were not explored as a part of this study, but should be considered and carefully evaluated in future studies.

It is also possible, particularly with regard to SI and TLV for HAL score associations with DUE MSDs, that the exposure level that causes one specific DUE MSD might be different than the exposure level that causes other specific DUE MSDs. This might help explain why reported SI cut-points are different from study to study and why the fixed cut-points for the TLV for HAL sometimes work and sometimes do not work.

If each specific DUE MSD is associated with a unique exposure to physical stressors, it would add additional variability to the exposure-response relationship between physical exposure and aggregate DUE MSDs. This additional variability might make dramatic increases in sample size necessary in order to quantify the relationship between SI, TLV for HAL, and incident of aggregate DUE MSDs. Once more studies of specific DUE MSDs have been completed, researchers will have a better understanding of the various exposure-response relationships and would be better able to recruit appropriate sample sizes.

Another possible explanation for the poor associations between physical exposure and aggregate DUE MSDs in this study is the effect of gender. As suggested by Silverstein, Fan, Smith, Bao, Howard, Spielholz, Bonauto, & Viikari-Juntura (2009), the exposure-response relationship might be different between males and females. Thus, gender might be an effect modifier; masking the association between aggregate DUE MSDs and physical exposure. By analyzing males and females together, we might have missed associations that would be apparent if we were to analyze each gender separately.

It is also possible that we simply did not follow the virgin cohort long enough for an association between physical exposure and aggregate DUE MSDs to properly develop. The mean age difference between the virgin and prevalent cohorts is five years (though not statistically significant), with the virgin cohort the younger of the two. As people age, changes occur to both tendons and muscle (ie vascular, collagen fibers increase in diameter and decrease in tensile strength, decrease in tendon elasticity, etc.), which makes these people more susceptible to sustaining an injury (Kannus & J□sza, 1991; Renström & Woo, 2008). Thus, there might be a tendency for younger workers to “resist” injury, even at relatively high exposure. While this study had a relatively long follow-up period (mean of 2.6 years) compared to other MSD studies, there was still not much time for workers to age or increase years of exposure. It is possible that with increased follow-up time, better relationships between physical exposure and aggregate DUE MSDs could be found.

Age, Gender, and BMI as Risk Factors for First Aggregate DUE MSD

Various studies have suggested that certain covariates may be associated with increased risk of various DUE MSDs (Garg, et al., 2012; Gardner, Dale, VanDillen, Franzblau, & Evanoff, 2008). This study found evidence of increased risk of aggregate DUE MSDs for age and gender (Table 4). Age was statistically significant in both univariate (HR = 1.03, 95% CI = 1.01 – 1.05, *p* = 0.001) and multivariate analysis (HR = 1.03, 95% CI = 1.01 – 1.05, *p* = 0.003). These results are consistent with previous research (English, et al., 1995; Ohlsson, et. al., 1994). Female gender was also statistically significant in both univariate (HR = 2.38, 95% CI = 1.36 – 4.17, *p* = 0.002) and multivariate analysis (HR = 2.26, 95% CI = 1.29 – 3.96, *p* = 0.004). This result is also consistent with the literature (Bernard, et al., 1994; Chiang, et al., 1993; Hales, et al., 1994; Johansson, 1994; Stevens, et al., 1988). No association was found between BMI and risk of DUE MSDs. This was unexpected as multiple studies report increased risk with increasing BMI (Leclerc, et al., 2001; Shiri, et al., 2006; Violante, et al., 2007). It should be noted that as age increases, so does BMI (Jackson, Stanforth, Gagnon, Rankinen, Leon, Rao, Skinner, Bouchard, & Wilmore, 2002). This study would suggest that it is increasing age, rather than increasing BMI that is driving the increased risk of DUE MSDs.

Differences among the Virgin and Prevalent Cohorts

There were gender and BMI differences found among the virgin and prevalent cohorts. The virgin cohort was more male in comparison to the prevalent cohort. This was expected because female gender is a risk factor for DUE MSDs; therefore, females are more likely to become injured and thus less likely to populate a virgin cohort (Bernard, et al. 1994, Hales, et al. 1994, Johansson 1994, Chiang, et al., 1993, Stevens, 1988). Age was not significantly different between groups. However, a 5 year age difference was observed, with the virgin cohort being the younger group. This is expected, since the likelihood of becoming injured increases with increased exposure (i.e. years on the job (Descatha, et al., 2003; Forde, Punnett, & Wegman, 2005; Silverstein, et al., 1987). Additionally, the virgin cohort had a slightly smaller BMI. However, this difference is very small (1.6 units) and both groups would be considered overweight on average. This small difference may exist because the virgin cohort is slightly younger in comparison and some studies have found that BMI increases with age (Jackson, et al., 2002). The strong statistical associations between age and gender in this study reinforce their importance as risk factors for DUE MSDs. The strong associations further suggest that stratified analyses based on these variables might be needed to better understand the association between physical stress and incidence of DUE MSDs. However, such studies would be difficult due to the large increases in sample size that stratification would require (particularly for age).

Development of MSDs in a Virgin Cohort

Of the virgin cohort, 24 (35%) participants developed multiple disorders. Only the disorders that developed first were analyzed in the current study. However, it is interesting to look at the order of occurrence for these disorders. Lateral epicondylitis, trigger finger, and CTS were typically the first disorders to develop among members of the virgin cohort. This is consistent with the suggestion from literature that these disorders are the most prevalent DUE MSDs. Among the disorders that developed after the first occurring DUE MSD, trigger finger was the most common (18), followed by all other disorders, which each had 2 or 3 cases each. There were three workers that developed as a third disorder, two of those disorders were deQuervains and one was lateral epicondylitis. There were not enough cases to draw any conclusions about why these disorders would develop as a third diagnosis.

Strengths, Weaknesses, and Limitations of the Study

This study's strengths include: prospective methods, enrollment of a fairly large number of workers from diverse work settings, assessment and measurement of three important covariates, reliance on NCSs at baseline and follow-ups, exclusions of pre-existing or prevalent cases and cases involving arthritis and/or hand procedures (i.e. hand surgery), detailed quantification of job physical factors, blinding of team members, monthly health status follow-ups, quarterly job physical assessment follow-ups of the cohort and moderately long follow-up of the cohort. These methods appear to have resulted in strong measures of effect for age, gender, and BMI.

Study design limitations include that workers were primarily from manufacturing settings, which make the results less generalizable to other environments. Also, other important covariates (such as physical activities performed outside of work and psychosocial factors) that may have contributed to the development of aggregate DUE MSDs were not evaluated.

Regarding specific weaknesses, while the use of a virgin cohort in this study is considered to be a strength of design, it also greatly reduced the number of eligible participants. The resulting limited sample size may have reduced our ability to demonstrate statistically significant results among job physical factors. It is also possible that the definition of “virgin cohort” was too strict. For example, workers who were told in the past by their physician that they had CTS were excluded from this study; even if they did not meet the case definition for CTS at baseline. CTS is often miss-diagnosed, thus it is likely that several of the workers excluded based on having been told by their physician that they had CTS should have been eligible. The same scenario may be happening with other DUE MSDs as well. In the future, researchers should consider a “virgin cohort” definition that only excludes those workers that have an aggregate DUE MSD at baseline (i.e. meets the case definition), or have had surgery to treat a DUE MSD in the past (e.g. carpal tunnel release). Such a change in exclusion criteria would lead to an increase in sample size and could affect results.

Similarly, the strict case definitions (i.e. symptoms plus positive physical maneuver) used to determine cases in the current study may have ignored workers that would have been classified as cases in a clinical setting. The more strict definitions used to identify very specific disorders might be helpful to determine etiology for those disorders, but softer definitions would catch very specific disorders as well as other disorders (both different as well as less severe) and would probably be of more value to industry where the goal is to avoid all DUE injuries, not just certain specific DUE MSDs. It is unclear what effect using softer case definitions might have had on the results of this study as both the eligible participants and the incident cases would be changed, perhaps considerably.

Future Studies

It is important to further investigate the SI and TLV for HAL's relationship in predicting aggregate DUE MSDs within a virgin cohort. More studies of specific DUE MSDs must be completed, so that researchers and employers attain a better understanding of the various exposure-response relationships for DUE MSDs and researches better know appropriate sample size requirements for studies of aggregate DUE MSDs. Future studies should also pursue longer follow-up times, so that workers of a virgin cohort are able to become older and increase their years of exposure (potentially allowing for the study of interactions between age and physical exposure).

The protective effect of force that was found in the current study, suggests that interactions between levels of force and the frequency and duration of those force levels should be specifically analyzed. Other interactions should be either directly or indirectly studied as well, such as the interaction between physical exposure and gender, and physical exposure and age. This would likely require much larger sample sizes than have been employed in the past.

Findings from prospective cohort studies of DUE MSDs are beneficial for researchers as they provide insight to the etiology of DUE MSDs as well as what measures of biomechanical stressors (e.g. the SI and TLV for HAL) reliably predict incidence of aggregate DUE MSDs, particularly in a virgin cohort. Information on what tools reliably quantify physical stressors that lead to DUE MSDs would be of great benefit to employers as they identify safe versus hazardous jobs, and strive to design safe, productive jobs for their workforce.

Conclusion

This study demonstrates that age and gender are strong risk factors for the development of first lifetime aggregate DUE MSDs. Mixed results were found for the SI when using both univariate and multivariate analysis, suggesting that the SI might be a more reliable method to use to detect jobs that lead to DUE MSDs than the TLV for HAL (which showed only non-significant results). Future studies with a larger cohort will determine the true associations between the SI and the TLV for HAL and first lifetime aggregate DUE MSDs within a virgin cohort.

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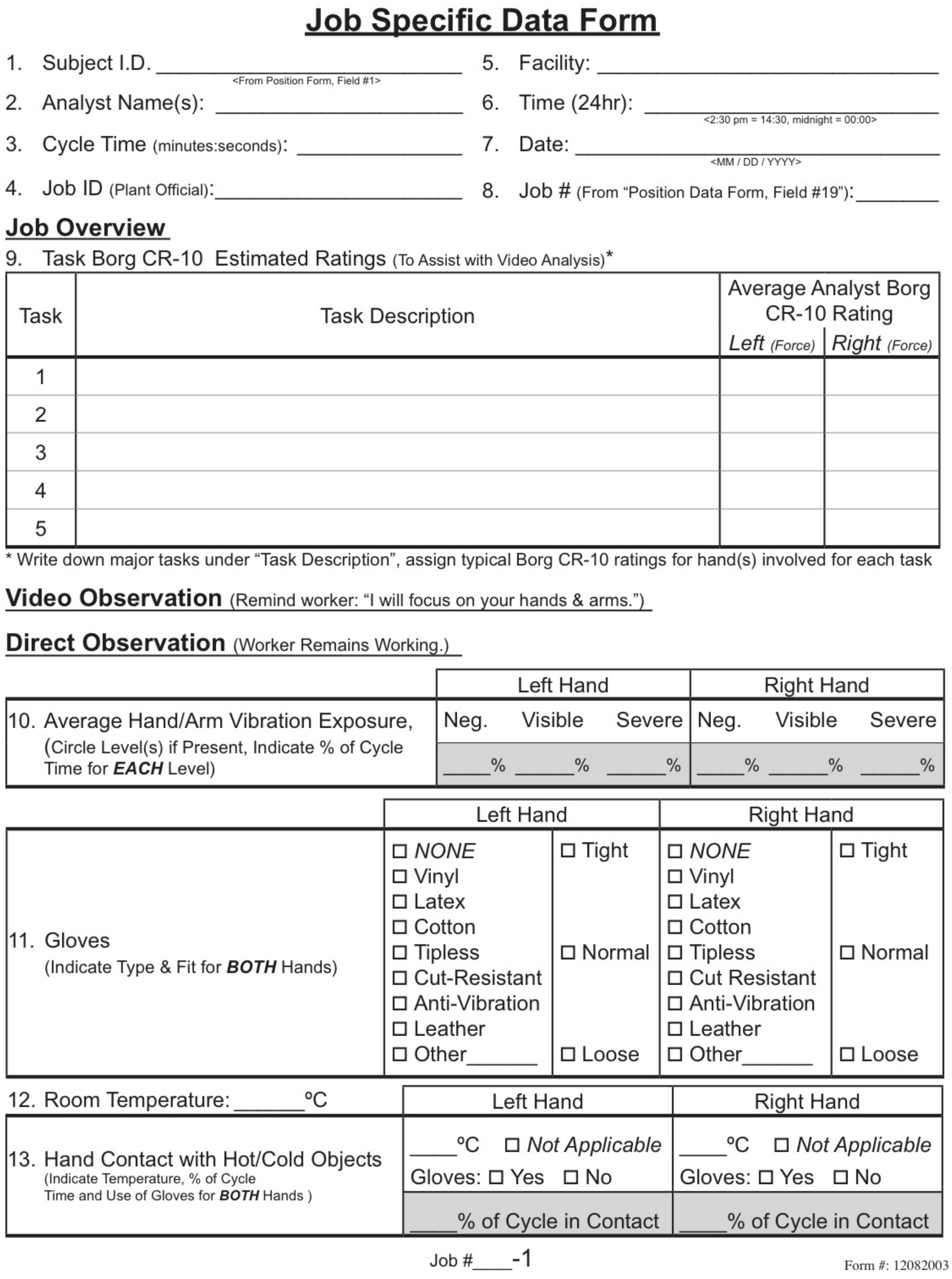
Appendix A1: Forms Used for Baseline Job Information



Job Specific Data Form

1. Subject I.D. ______________________________ <From Position Form, Field #1>
2. Analyst Name(s): ______________________
3. Cycle Time (minutes:seconds): _______________
4. Job ID (Plant Official):______________________
5. Facility: ______________________________
6. Time (24hr): ________________________ <2:30 pm = 14:30, midnight = 00:00>
7. Date: _________________________________ <MM / DD / YYYY>
8. Job # (From "Position Data Form, Field #19"):________

Job Overview

9. Task Borg CR-10 Estimated Ratings (To Assist with Video Analysis)*

Task	Task Description	Average Analyst Borg CR-10 Rating	
		Left *(Force)*	*Right* *(Force)*
1			
2			
3			
4			
5			

* Write down major tasks under "Task Description", assign typical Borg CR-10 ratings for hand(s) involved for each task

Video Observation (Remind worker: "I will focus on your hands & arms.")

Direct Observation (Worker Remains Working.)

	Left Hand			Right Hand		
10. Average Hand/Arm Vibration Exposure, (Circle Level(s) if Present, Indicate % of Cycle Time for ***EACH*** Level)	Neg.	Visible	Severe	Neg.	Visible	Severe
	_____%	______%	______%	_____%	______%	______%

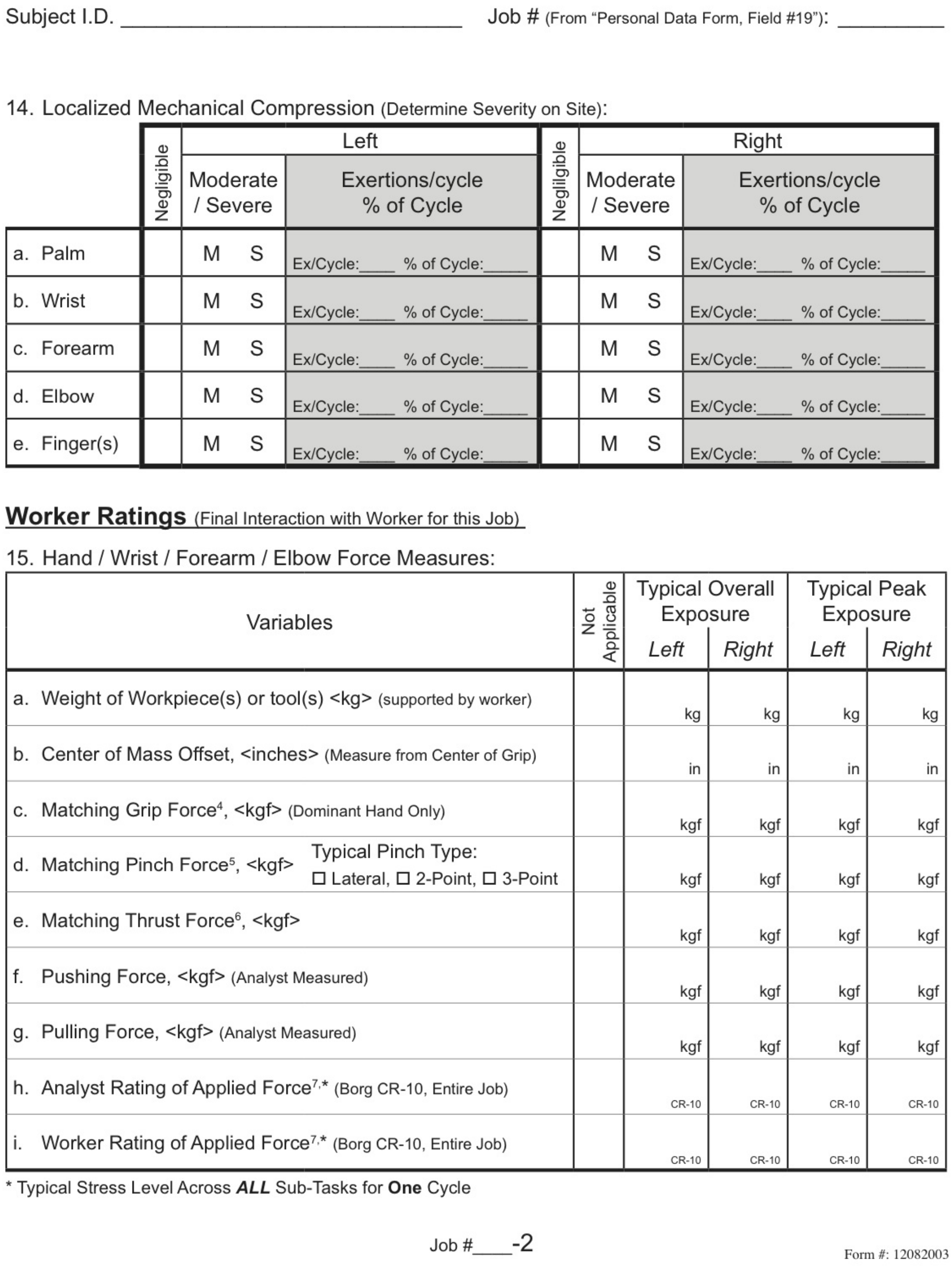
	Left Hand		Right Hand	
11. Gloves (Indicate Type & Fit for ***BOTH*** Hands)	☐ *NONE* ☐ Vinyl ☐ Latex ☐ Cotton ☐ Tipless ☐ Cut-Resistant ☐ Anti-Vibration ☐ Leather ☐ Other______	☐ Tight ☐ Normal ☐ Loose	☐ *NONE* ☐ Vinyl ☐ Latex ☐ Cotton ☐ Tipless ☐ Cut Resistant ☐ Anti-Vibration ☐ Leather ☐ Other______	☐ Tight ☐ Normal ☐ Loose

12. Room Temperature: ______ºC	Left Hand	Right Hand
13. Hand Contact with Hot/Cold Objects (Indicate Temperature, % of Cycle Time and Use of Gloves for ***BOTH*** Hands)	____ºC ☐ *Not Applicable* Gloves: ☐ Yes ☐ No	____ºC ☐ *Not Applicable* Gloves: ☐ Yes ☐ No
	____% of Cycle in Contact	____% of Cycle in Contact

Job #____-1

Form #: 12082003

Appendix A2: Forms Used for Baseline Job Information



Subject I.D. ______________________________ Job # (From "Personal Data Form, Field #19"): __________

14. Localized Mechanical Compression (Determine Severity on Site):

	Left			Right		
	Negligible	Moderate / Severe	Exertions/cycle % of Cycle	Negligible	Moderate / Severe	Exertions/cycle % of Cycle
a. Palm		M S	Ex/Cycle:____ % of Cycle:_____		M S	Ex/Cycle:____ % of Cycle:_____
b. Wrist		M S	Ex/Cycle:____ % of Cycle:_____		M S	Ex/Cycle:____ % of Cycle:_____
c. Forearm		M S	Ex/Cycle:____ % of Cycle:_____		M S	Ex/Cycle:____ % of Cycle:_____
d. Elbow		M S	Ex/Cycle:____ % of Cycle:_____		M S	Ex/Cycle:____ % of Cycle:_____
e. Finger(s)		M S	Ex/Cycle:____ % of Cycle:_____		M S	Ex/Cycle:____ % of Cycle:_____

Worker Ratings (Final Interaction with Worker for this Job)

15. Hand / Wrist / Forearm / Elbow Force Measures:

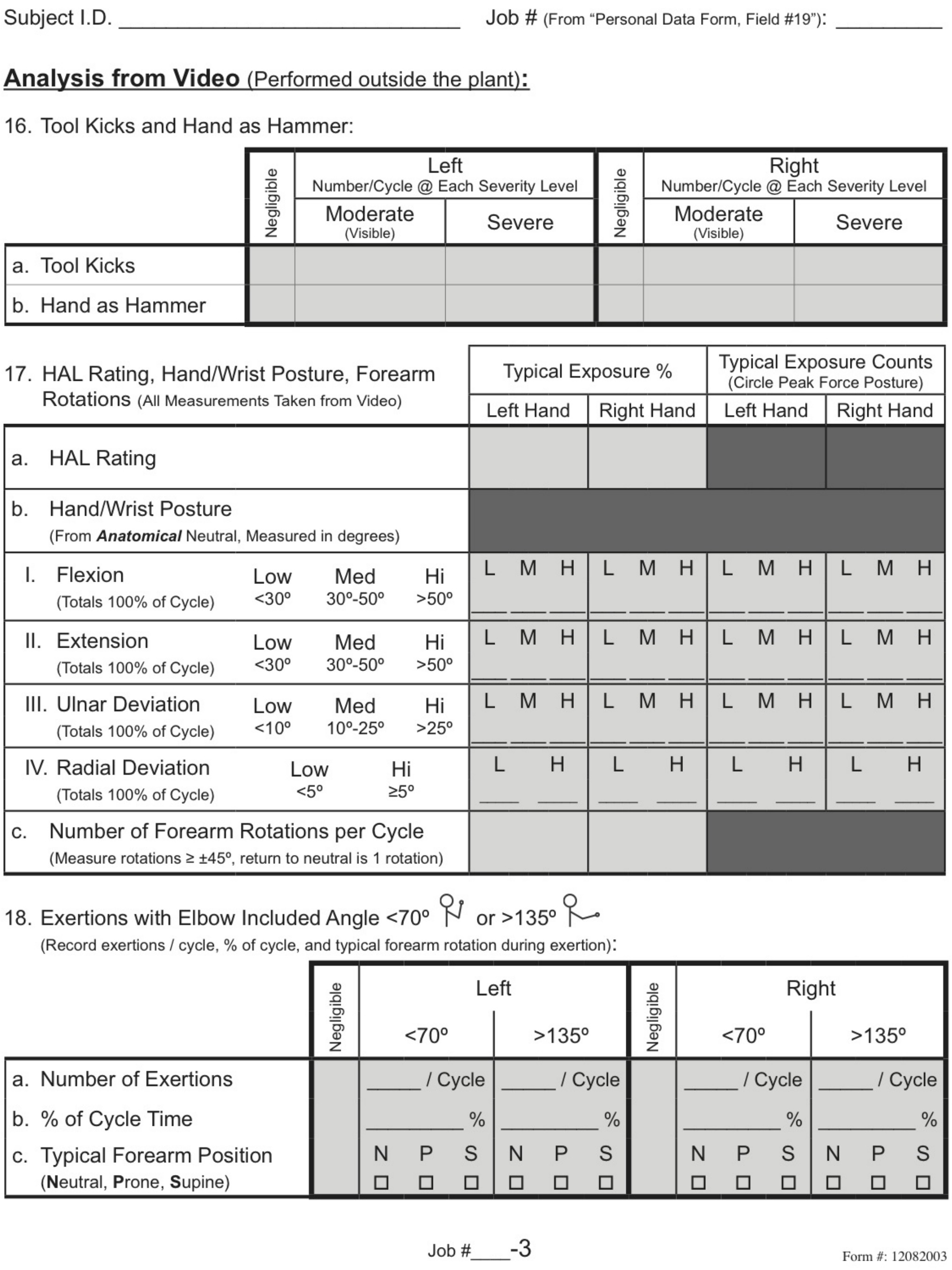
Variables	Not Applicable	Typical Overall Exposure		Typical Peak Exposure	
		Left	*Right*	*Left*	*Right*
a. Weight of Workpiece(s) or tool(s) <kg> (supported by worker)		kg	kg	kg	kg
b. Center of Mass Offset, <inches> (Measure from Center of Grip)		in	in	in	in
c. Matching Grip Force[4], <kgf> (Dominant Hand Only)		kgf	kgf	kgf	kgf
d. Matching Pinch Force[5], <kgf> Typical Pinch Type: ☐ Lateral, ☐ 2-Point, ☐ 3-Point		kgf	kgf	kgf	kgf
e. Matching Thrust Force[6], <kgf>		kgf	kgf	kgf	kgf
f. Pushing Force, <kgf> (Analyst Measured)		kgf	kgf	kgf	kgf
g. Pulling Force, <kgf> (Analyst Measured)		kgf	kgf	kgf	kgf
h. Analyst Rating of Applied Force[7,*] (Borg CR-10, Entire Job)		CR-10	CR-10	CR-10	CR-10
i. Worker Rating of Applied Force[7,*] (Borg CR-10, Entire Job)		CR-10	CR-10	CR-10	CR-10

* Typical Stress Level Across ***ALL*** Sub-Tasks for **One** Cycle

Job #____-2

Form #: 12082003

Appendix A3: Forms Used for Baseline Job Information



Subject I.D. ______________________________ Job # (From "Personal Data Form, Field #19"): __________

Analysis from Video (Performed outside the plant)**:**

16. Tool Kicks and Hand as Hammer:

	Left			Right		
	Negligible	Number/Cycle @ Each Severity Level Moderate (Visible)	Severe	Negligible	Number/Cycle @ Each Severity Level Moderate (Visible)	Severe
a. Tool Kicks						
b. Hand as Hammer						

17. HAL Rating, Hand/Wrist Posture, Forearm Rotations (All Measurements Taken from Video)		Typical Exposure %		Typical Exposure Counts (Circle Peak Force Posture)	
		Left Hand	Right Hand	Left Hand	Right Hand
a. HAL Rating					
b. Hand/Wrist Posture (From ***Anatomical*** Neutral, Measured in degrees)					
I. Flexion (Totals 100% of Cycle)	Low <30° Med 30°-50° Hi >50°	L M H ___ ___ ___	L M H ___ ___ ___	L M H ___ ___ ___	L M H ___ ___ ___
II. Extension (Totals 100% of Cycle)	Low <30° Med 30°-50° Hi >50°	L M H ___ ___ ___	L M H ___ ___ ___	L M H ___ ___ ___	L M H ___ ___ ___
III. Ulnar Deviation (Totals 100% of Cycle)	Low <10° Med 10°-25° Hi >25°	L M H ___ ___ ___	L M H ___ ___ ___	L M H ___ ___ ___	L M H ___ ___ ___
IV. Radial Deviation (Totals 100% of Cycle)	Low <5° Hi ≥5°	L H ____ ____	L H ____ ____	L H ____ ____	L H ____ ____
c. Number of Forearm Rotations per Cycle (Measure rotations ≥ ±45°, return to neutral is 1 rotation)					

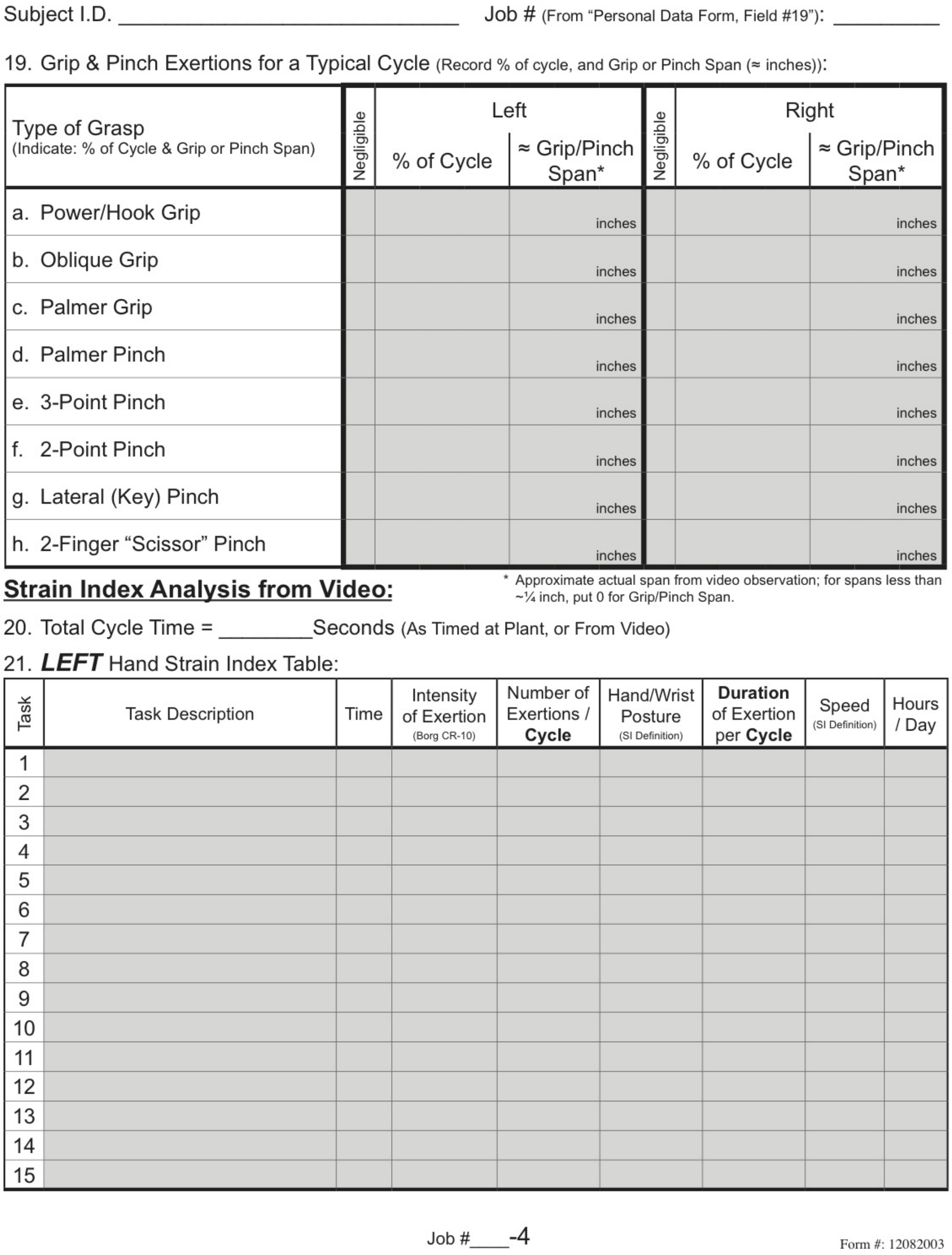
18. Exertions with Elbow Included Angle <70° or >135°
(Record exertions / cycle, % of cycle, and typical forearm rotation during exertion):

	Left			Right		
	Negligible	<70°	>135°	Negligible	<70°	>135°
a. Number of Exertions		_____ / Cycle	_____ / Cycle		_____ / Cycle	_____ / Cycle
b. % of Cycle Time		_________ %	_________ %		_________ %	_________ %
c. Typical Forearm Position (**N**eutral, **P**rone, **S**upine)		N ☐ P ☐ S ☐	N ☐ P ☐ S ☐		N ☐ P ☐ S ☐	N ☐ P ☐ S ☐

Job #____-3

Form #: 12082003

Appendix A4: Forms Used for Baseline Job Information



Subject I.D. ______________________________ Job # (From “Personal Data Form, Field #19”): __________

19. Grip & Pinch Exertions for a Typical Cycle (Record % of cycle, and Grip or Pinch Span (≈ inches)):

Type of Grasp (Indicate: % of Cycle & Grip or Pinch Span)	Negligible	Left		Negligible	Right	
		% of Cycle	≈ Grip/Pinch Span*		% of Cycle	≈ Grip/Pinch Span*
a. Power/Hook Grip			inches			inches
b. Oblique Grip			inches			inches
c. Palmer Grip			inches			inches
d. Palmer Pinch			inches			inches
e. 3-Point Pinch			inches			inches
f. 2-Point Pinch			inches			inches
g. Lateral (Key) Pinch			inches			inches
h. 2-Finger “Scissor” Pinch			inches			inches

* Approximate actual span from video observation; for spans less than ~¼ inch, put 0 for Grip/Pinch Span.

Strain Index Analysis from Video:

20. Total Cycle Time = ________Seconds (As Timed at Plant, or From Video)

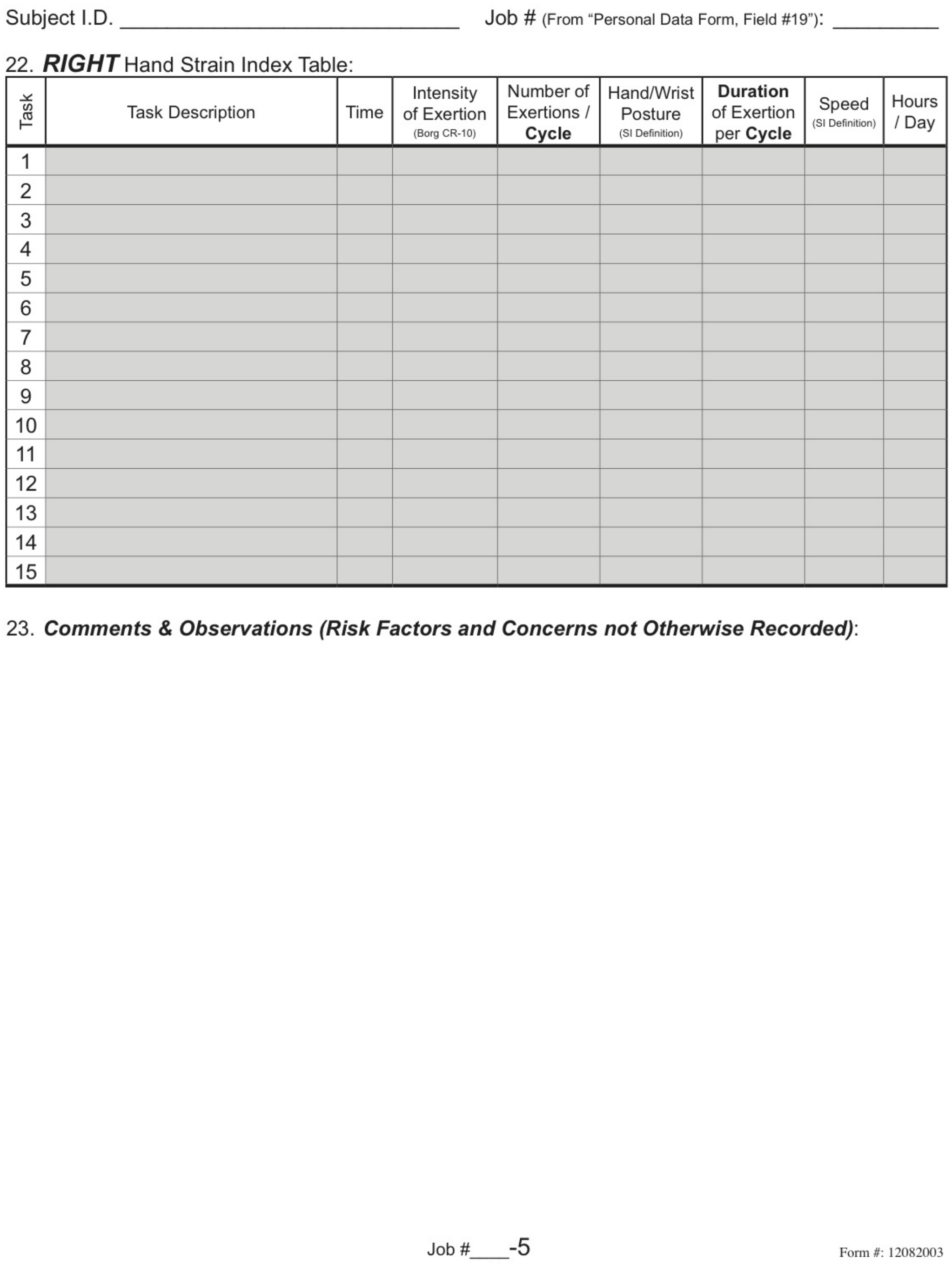
21. ***LEFT*** Hand Strain Index Table:

Task	Task Description	Time	Intensity of Exertion (Borg CR-10)	Number of Exertions / **Cycle**	Hand/Wrist Posture (SI Definition)	**Duration** of Exertion per **Cycle**	Speed (SI Definition)	Hours / Day
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

Job #____-4

Form #: 12082003

Appendix A5: Forms Used for Baseline Job Information



Subject I.D. ______________________________ Job # (From “Personal Data Form, Field #19”): __________

22. ***RIGHT*** Hand Strain Index Table:

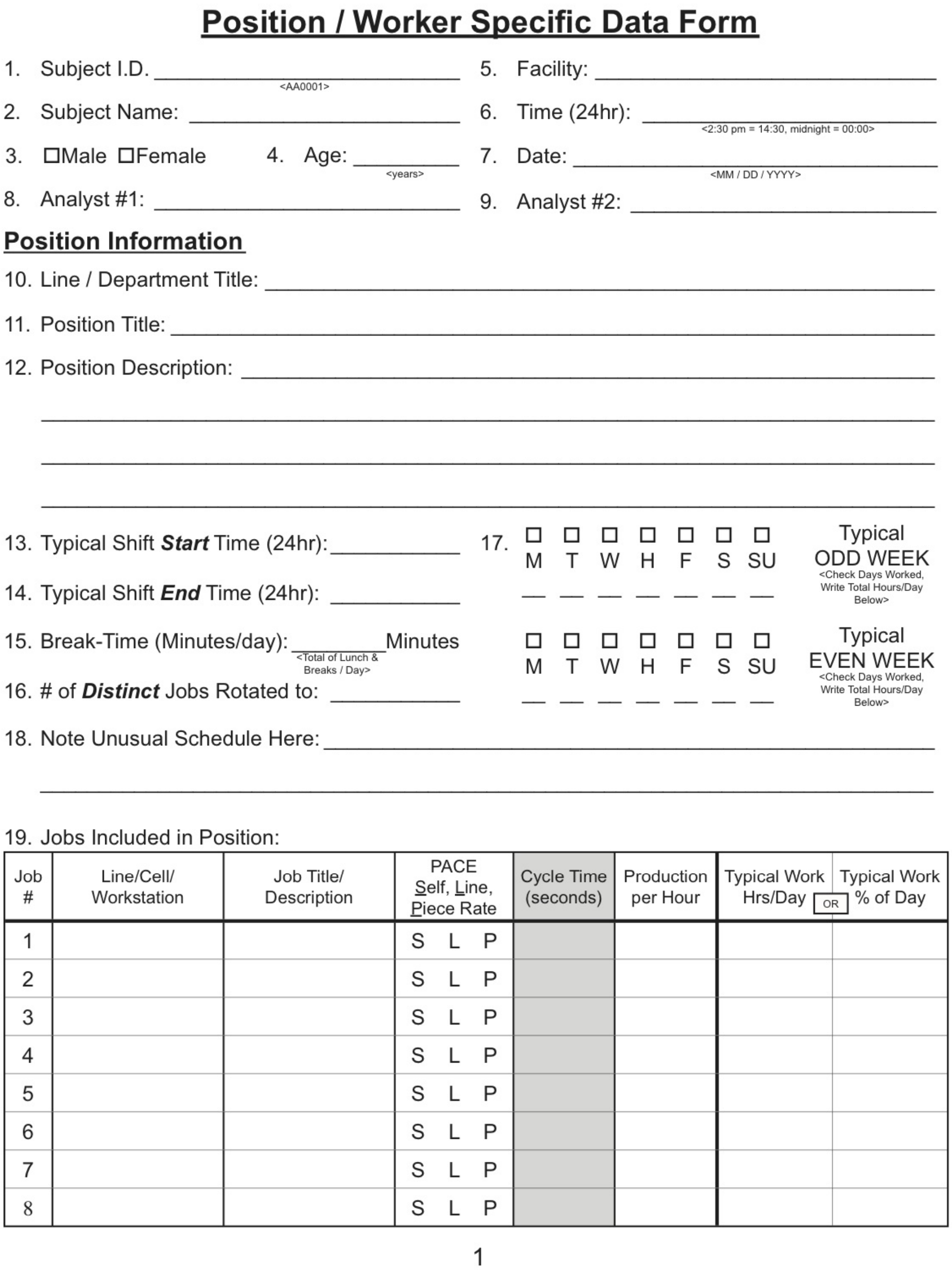
Task	Task Description	Time	Intensity of Exertion (Borg CR-10)	Number of Exertions / **Cycle**	Hand/Wrist Posture (SI Definition)	**Duration** of Exertion per **Cycle**	Speed (SI Definition)	Hours / Day
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

23. ***Comments & Observations (Risk Factors and Concerns not Otherwise Recorded)***:

Job #____-5

Form #: 12082003

Appendix A6: Forms Used for Baseline Job Information



Position / Worker Specific Data Form

1. Subject I.D. ______________________ <AA0001>
2. Subject Name: ______________________
3. ☐Male ☐Female
4. Age: ________ <years>
5. Facility: ______________________
6. Time (24hr): ______________________ <2:30 pm = 14:30, midnight = 00:00>
7. Date: ______________________ <MM / DD / YYYY>
8. Analyst #1: ______________________
9. Analyst #2: ______________________

Position Information

10. Line / Department Title: ______________________
11. Position Title: ______________________
12. Position Description: ______________________

____

____

____

13. Typical Shift ***Start*** Time (24hr): ___________
14. Typical Shift ***End*** Time (24hr): ___________
15. Break-Time (Minutes/day): ________ Minutes <Total of Lunch & Breaks / Day>
16. # of ***Distinct*** Jobs Rotated to: ___________
17.

☐	☐	☐	☐	☐	☐	☐	Typical
M	T	W	H	F	S	SU	ODD WEEK <Check Days Worked, Write Total Hours/Day Below>
__	__	__	__	__	__	__	
☐	☐	☐	☐	☐	☐	☐	Typical
M	T	W	H	F	S	SU	EVEN WEEK <Check Days Worked, Write Total Hours/Day Below>
__	__	__	__	__	__	__	

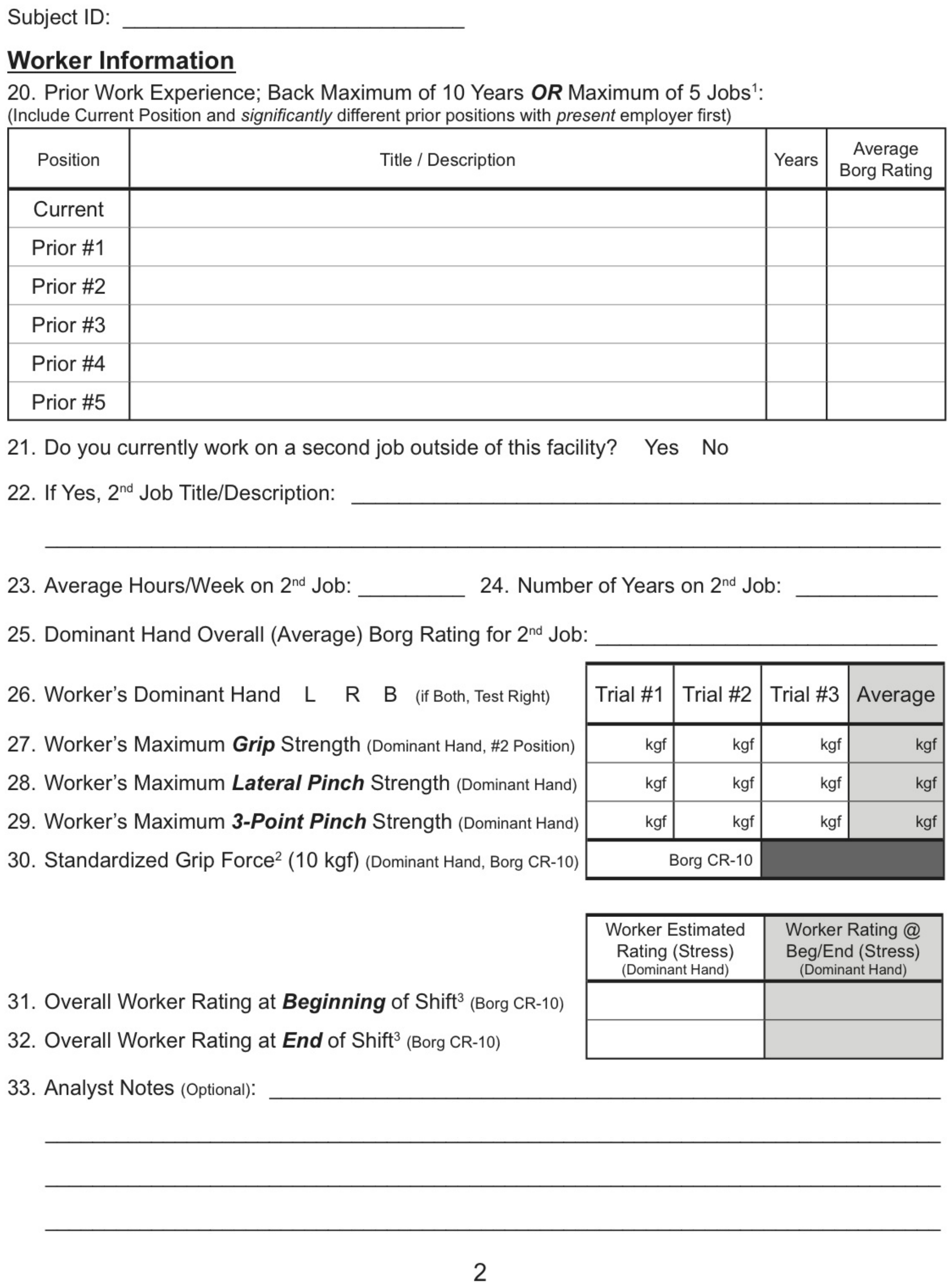
18. Note Unusual Schedule Here: ______________________

____

19. Jobs Included in Position:

Job #	Line/Cell/ Workstation	Job Title/ Description	PACE Self, Line, Piece Rate	Cycle Time (seconds)	Production per Hour	Typical Work Hrs/Day OR	Typical Work % of Day
1			S L P				
2			S L P				
3			S L P				
4			S L P				
5			S L P				
6			S L P				
7			S L P				
8			S L P				

Appendix A7: Forms Used for Baseline Job Information



Subject ID: ____________________________

Worker Information

20. Prior Work Experience; Back Maximum of 10 Years ***OR*** Maximum of 5 Jobs[1]:
(Include Current Position and *significantly* different prior positions with *present* employer first)

Position	Title / Description	Years	Average Borg Rating
Current			
Prior #1			
Prior #2			
Prior #3			
Prior #4			
Prior #5			

21. Do you currently work on a second job outside of this facility? Yes No

22. If Yes, 2nd Job Title/Description: ____

____

23. Average Hours/Week on 2nd Job: _________ 24. Number of Years on 2nd Job: ___________

25. Dominant Hand Overall (Average) Borg Rating for 2nd Job: ___________________________

	Trial #1	Trial #2	Trial #3	Average
26. Worker's Dominant Hand L R B (if Both, Test Right)				
27. Worker's Maximum ***Grip*** Strength (Dominant Hand, #2 Position)	kgf	kgf	kgf	kgf
28. Worker's Maximum ***Lateral Pinch*** Strength (Dominant Hand)	kgf	kgf	kgf	kgf
29. Worker's Maximum ***3-Point Pinch*** Strength (Dominant Hand)	kgf	kgf	kgf	kgf
30. Standardized Grip Force[2] (10 kgf) (Dominant Hand, Borg CR-10)	Borg CR-10			

	Worker Estimated Rating (Stress) (Dominant Hand)	Worker Rating @ Beg/End (Stress) (Dominant Hand)
31. Overall Worker Rating at ***Beginning*** of Shift[3] (Borg CR-10)		
32. Overall Worker Rating at ***End*** of Shift[3] (Borg CR-10)		

33. Analyst Notes (Optional): ____

____

____

____

Appendix B: Force Algorithm

Description of Algorithm:

For each task, review all sub-tasks stratified by Borg CR-10 force rating (0.5-10). Beginning with the highest Borg CR-10 rated sub-task, look up the minimum possible overall Borg CR-10 rating based on average duration per exertion and frequency of exertion at that force level. Continue evaluating each force level in descending order until the minimum possible overall force is the same as or grater than the force level currently being evaluated. Use the final overall force Borg CR-10 rating in all SI calculations. Borg CR-10 ratings are converted to SI ratings using their respective verbal anchor scales.

Rules used during the performance of the algorithm are below:

1. During analysis, ignore efforts with Borg CR-10 ratings equal to 0 or 0.5 (note: these efforts should be extracted from video). These should not be counted when calcuating efforts per minute and percent duration of exertion.
2. After step 1, if all efforts are at a single Borg CR-10 rating, then use that force rating.
3. If ≥ 40% of efforts are at the maximum task Borg rating, then assign that Borg rating as the overall task force rating.
4. If ≥ 40% of duty cycle is at the maximum task Borg rating, then assign that Borg rating as the overall task rating.
5. Peak force exertions less often than once per five minutes ($F<0.2/min$) are ignored unless duration is greater than 5 seconds.
6. When counting exertions at force less than peak force, count all exertions that occur at and above that force level. Use duration of exertion from the current force.
7. When using tables, cross interpolate between nearest four cells (rows and columns). Values should be rounded to the nearest integer. Values at x.50 should round DOWN.

*For specific algorithm charts, contact author at tacash85@aol.com