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# Using Observations from the UAW-Ford Ergonomic Assessment Tool to Predict Distal Upper Extremity Musculoskeletal Disorders

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# Using Observations from the UAW-Ford Ergonomic Assessment Tool to Predict Distal Upper Extremity Musculoskeletal Disorders

by

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## Dedication

This thesis is dedicated to my parents, Darlene Powell and Lisa Brandes. Thank you for your unwavering love, support, and encouragement.

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**Table of Contents**

**List of Tables**

## List of Abbreviations & Acronyms

| | |
|---|---|
| ACGIH® | American Conference of Governmental Industrial Hygienists |
| AUC | Area Under the Curve |
| BLS | Bureau of Labor Statistics |
| CDC | Centers for Disease Control and Prevention |
| CTS | Carpal Tunnel Syndrome |
| DUE | Distal Upper Extremity |
| EST | Ergonomic Surveillance Tool |
| HA | Hand Activity |
| HAL | Hand Activity Level |
| MSD | Musculoskeletal Disorder |
| MVC | Maximum Voluntary Contraction |
| NIOSH | National Institutes for Occupational Safety and Health |
| OSHA | Occupational Safety and Health Administration |
| REBA | Rapid Entire Body Assessment |
| ROC | Receiver Operating Characteristic |
| RSI | Revised Strain Index |
| RULA | Rapid Upper Limb Assessment |
| SI | Strain Index |
| TLV® | Threshold Limit Value |
| TWA | Time Weighted Average |
| UAW | United Auto Workers Union |
| USF | University of South Florida |

**Abstract**

Distal upper extremity (DUE) musculoskeletal disorders (MSDs) affect thousands of workers annually. Job tasks can have a significant amount of MSD risk depending on the presence of certain risk factors The UAW-Ford Ergonomic Surveillance Tool (EST) is a method specifically designed for the UAW and Ford Motor Company to assess MSD risk in its facilities. The purpose of this report is to evaluate which risk factors in the UAW-Ford EST predict the risk of developing DUE MSDs. Data collected by a previous study on four UAW-Ford automotive manufacturing plants were analyzed. Target jobs were selected based on associated First Time Occupational Visit (FTOV) to the plant clinic or a red flag by the EST. About 50 interviews at each plant were conducted to determine if operators experienced pain or discomfort and if treatment was sought outside of the plant. Risk factors were tested as dichotomous variables representing low and high exposure groups, or the presence or absence of a risk factor and applying logistic regression using the data from the EST.

The presence of impulse loading ($p < 0.01$) had a sensitivity of 0.49 and a specificity of 1.00. Marked hand posture ($p = 0.02$) had a sensitivity of 1.0 and a specificity of 0.09. High repetition ($p = 0.13$) had a sensitivity of 0.89 and a specificity of 0.48. Presence of vibration ($p = 0.78$) had a sensitivity of 0.43 and a specificity of 0.72. The combination of hand posture and repetition represented by an estimated Peak Force Index ($PFI_{TLV}$) ($p < 0.01$) had a sensitivity of 0.88 and a specificity of 0.48. When impulse loading and hand posture were modeled together in a logistic regression, they had good ability to discriminate between cases and non-cases (AUC =0.84). This remained true when $PFI_{TLV}$ and impulse were modeled together (AUC =0.85). This analysis indicates that impulse loading in manufacturing jobs and poor hand postures are associated with DUE MSDs.

## Chapter One:

## Introduction

Musculoskeletal disorders (MSDs) are a significant burden to the workforce, healthcare system, and economy of the United States. These disorders accounted for roughly one third of occupational injuries and illnesses resulting in days away from work annually from 1992-2013 (Bhattacharya, 2014). In addition to their prevalence MSD cases are, on average, more severe than nonfatal injuries or illnesses (Centers for Disease Control and Prevention [CDC], n.d.). In 2018, the median days away from work for MSDs in private industry was 12 days (Bureau of Labor Statistics [BLS], 2018a), which was four more days than the median for all nonfatal workplace injuries in the same year (BLS, 2018b). The burden of MSDs on the American healthcare system is also immense. Musculoskeletal injury and illness generate an estimated 130 million total health care encounters each year and 70 million physician office visits (CDC, n.d.). These injuries are associated with a combined direct and indirect cost to employers estimated to be as large as $3.4 billion dollars (Bhattacharya, 2014) as well as an overall economic impact of $45 billion (CDC, n.d.).

Distal upper extremity MSDs (DUE MSDs) represent a subset of MSDs which are specific to the elbow, forearm, wrist, hand, and fingers (Garg & Kapellusch, 2011). DUE MSDs include non-specific pain, carpal tunnel syndrome (CTS), hand/wrist tendinitis, lateral epicondylitis, and trigger digit. In 2018, DUE disorders accounted for more than 30% of MSDs in private industry and had a median time away from work 9 days longer than the median MSD days away for private industry (BLS). These health outcomes can have a serious and lasting impact on workers (Kapellusch et al., 2014b), for instance CTS may require surgery to treat which may alter wrist function permanently (Violante et al., 2016).

There are a variety of personal and work-related risk factors for the development of DUE MSDs that have been identified and continue to be studied. Personal risk factors for specific DUE MSDs can include gender, obesity age, and predisposing medical conditions such as rheumatoid arthritis and diabetes mellitus (Bonfiglioli et al., 2013; Franzblau et al., 2005; Garg et al., 2011, Kapellusch et al., 2014b). In occupational settings risk factors for upper extremity musculoskeletal injuries and illnesses include forceful exertion, non-neutral hand/wrist posture, contact pressure, duration of task, repetitiveness, exposure to cold temperatures, and vibration (CDC, n.d.; Franzblau et al., 2005; Garg et al., 2011, 2017; OSHA, n.d.a). There is strong evidence that combinations of these risk factors increase risk for MSDs such as CTS (Harris et al., 2011), Hand/Wrist Tendinitis, and Epicondylitis (National Institute for Occupational Safety and Health, 1997).

Accurate assessment of risk factors and employee exposure in the workplace is an important component of controlling or eliminating any hazardous condition. To this end, several ergonomic assessment tools have been created to aid in characterizing exposure and categorizing task risk. These tools include the ACGIH® Threshold Limit Value® for Hand Activity (ACGIH TLV® for HA), the Moore-Garg Strain Index (SI), Revised Strain Index (RSI), Rapid Upper Limb Assessment (RULA), and Rapid Entire Body Assessment (REBA). Each of these assessment tools considers some combination of work-related MSD risk factors. The assessment tools yield scores that are interpreted into a risk category ranging from safe/negligible risk to hazardous/high risk based on criterion scores specific to the tool (ACGIH, 2019; Ergonomics Plus Inc.[ErgoPlus], n.d.; Moore & Garg, 1995). These ergonomic assessment tools have been the subject of much study in the last twenty years to determine their reliability and predictive validity.

The United Auto Workers Union (UAW) – Ford Motor Company Ergonomic Surveillance Tool (EST) is an assessment tool specifically designed for the UAW and Ford to assess MSD risk in its facilities. The purpose of this thesis is to evaluate whether the UAW-Ford EST is able to predict the risk of developing DUE MSDs via the risk factors of hand/wrist posture, repetition, impulse loading, vibration, and TLV peak force index (PFI).

# Chapter Two:

# Literature Review

MSDs are the result of interactions between a number of complex factors, not all of which are well understood. Occupational risk factors common to DUE MSDs include forceful exertion, awkward posture, and repetition. Additional risk factors which may contribute to risk or modify occupational risk factors include static work, grip type, vibration, contact stress, and low temperatures (Garg et al., 2011, Kolgiri et al., 2011). Workers also carry their own amount of risk for MSDs based on demographic or personal risk factors. Age, sex, pregnancy, obesity, recreational activities, smoking, co-occurring medical conditions, and psychosocial factors have the potential to influence an individual's risk of developing a DUE MSD (ACGIH, 2019; Kapellusch, 2014a; NIOSH, 1997, 2014; Rucker & Moore, 2002). The risk factors for DUE MSD are hypothesized interact multiplicatively (Garg et al., 2011, 2017) so that a task requiring a combination of risk factors produces a much higher level of risk.

## Forceful exertion, posture, and repetitiveness

In ergonomics, force is defined as the effort needed to perform a task or to maintain control over an object (Jaffar et al., 2011). Static loading is associated with greater biomechanical strain as a result of combined high applied force, low frequency, and long duration exertions (Garg et al., 2017). The application of excessive force or static loading are widely considered risk factors for DUE MSDs (ACGIH, 2019; Garg et al., 2017; Jaffar et al., 2011; Kolgiri et al., 2016; NIOSH, 1997, 2014). Forceful exertions have been a long-identified risk factor for specific disorders including CTS, hand/wrist tendinitis, and lateral epicondylitis (Bernard, 1997; da Costa & Vieira, 2010). Work with extensive force requirements has also been identified as a significant contributor to non-specific upper limb MSDs in recent literature (da

Costa & Vieira, 2010). The intensity of exertion is a consideration in most DUE focused ergonomic assessment tools including the ACGIH TLV for HA, RULA, the SI and RSI. The SI and RSI also incorporate the duration and frequency of exertion when considering force as a risk factor.

The ACGIH TLV for HA uses the normalized peak force (NPF) to characterize exertion intensity during tasks (ACGIH, 2019). In theory, peak force as a measurement or estimation is thought to overestimate force in situations where a high peak force is applied for a small percentage of the overall exertion (Kapellusch et al., 2017). As a result, it may not be the most accurate measure of force, but it may be the most protective.

The SI and RSI evaluate the force requirement for a task as the percentage of maximum strength required to perform the task once (Garg et al., 2017) and therefore represents the overall force exerted. When examining the multipliers for each section of the SI, the intensity of exertion is given the most weight, receiving a multiplier of 13 for near maximal exertion (Moore & Garg, 1995). The RSI increased the multiplier to 30 for an applied force of near 100% maximum voluntary contraction (MVC) (Garg et al., 2017). The SI and RSI also consider the duration of forceful exertion, the former as the percentage of cycle time under exertion (Moore & Garg, 1995) and the later as the duration of exertion in seconds (Garg et al., 2017). The shift away from duty cycle to duration in seconds may allow the RSI to more accurately model the risk of tasks with static loading by combining exertion period with frequency (Garg et al., 2017).

Between RULA and REBA, force applied to the upper extremities is only considered by RULA. RULA also differs from the ACGIH TLV for HA and the SI/RSI by being the only metric that assesses force based on the weight of the load in the hand rather than through percent of maximum strength or percent MVC. RULA considers loading below 2 kg to be non-additive to risk (McAtamney & Corlett, 1993). The RULA assessment also considers static loading to be more hazardous than intermittent loading and assigns a higher modifier to exposures of the same weight category where static loading is present.

Non-neutral, also called awkward, postures of the wrist include flexion or extension, radial or ulnar deviation, and pronation or supination. Hand/wrist posture and the type of grip used has a direct effect on strength, where deviations from a posture of maximum grip strength have been estimated to result in a strength decrease of up to 42% (Kattel et al., 1996). The position of maximum grip strength is not agreed upon with some studies recommending the wrist remain in neutral posture (Kattel et al., 1996) while others suggest some degree of wrist extension is necessary (Garg et al., 2011). Regardless, the use of a pinch grip results in significantly lower strength than that of a power grip (Garg et al., 2011). Grip and wrist strength are also lower in flexion than extension (Garg et al., 2011, 2017) and were significantly reduced with forearm pronation (Garg et al., 2011, Kattel et al.,1996). Evidence from psychosocial studies has indicated that the maximum tolerable frequency of exertion is lower in wrist flexion than in neutral posture or extension (Garg et al., 2017) and that a combination of flexion and deviation can create high levels of discomfort (Carey & Gallwey, 2002).

Maintaining a non-neutral wrist posture has been associated with development of DUE MSDs, however there is insufficient evidence that it alone is a significant risk factor (Bernard, 1997; Garg et al., 2017). When analyzed in combination with force and repetitiveness there is strong evidence that sustained non-neutral posture increases risk DUE MSD (Garg et al., 2017) including lateral epicondylitis, hand/wrist tendinitis (Bernard, 1997; Garg et al., 2012) and CTS (Garg et al., 2012).

The ACGIH TLV for HA does not directly include hand/wrist posture in its analysis of ergonomic risk. In the 2019 TLV for Hand Activity it is explained that non-neutral posture is an indirect consideration as it will reduce strength and thereby increase normalized peak force (ACGIH, 2019). The SI includes a posture multiplier based on an ordinal weighting scale from neutral, multiplier of 1.0, to extreme, multiplier of 3.0 (Moore & Garg, 1995). The RSI includes an additional distinction when examining hand/wrist posture for when pinching/gripping force is applied in wrist extension or flexion (Garg et al., 2017).

RULA and REBA are the most comprehensive tools for posture analysis of those examined in this thesis. They include assessment of the positioning of the arm (in upper and lower segments) and the wrist which are input into a table to yield an overall posture score (Hignett & McAtamney, 2000; McAtamney & Corlett, 1993). The wrist posture score on these tools is primarily a function of whether or not the wrist is in flexion or extension. The presence of supination or pronation determines if the modifier for wrist twist is included in the score. This approach echoes research that the combination of deviations of the upper extremities results in reduced strength which may augment risks from forceful exertion.

Repetition consists of repeatedly performing the same or similar actions repeatedly (Jaffar et al., 2011). It has been demonstrated to be a risk factor for DUE MSDs as well as exacerbating the detrimental effects of tasks requiring high force, static loading, and awkward postures (Kolgiri et al., 2016; Latko, 1999). Repetition has been identified as a significant risk factor for non-specific pain (Latko et al., 1999), CTS (Bernard, 1997; Garg et al., 2012), hand/wrist tendinitis (Bernard, 1997) and a possible risk factor for trigger digit (Kapellusch, 2014a).

Ergonomic assessment tools assess repetition to varying degrees using different metrics. The ACGIH TLV for HA measures repetition through hand activity level which is a relationship between exertion frequency and duty cycle (ACGIH, 2019; Bao et al., 2006). The SI uses three variables to characterize the repetitiveness of analyzed tasks. These variables are duration of exertion, efforts per minute, and speed of work (Bao et al., 2006, Moore & Garg, 1995). The RSI also utilizes duration of exertion and efforts per minute but does not consider the speed of work (Garg et al., 2017). RULA and REBA include a modifier that applies to both static posture and actions performed more than four times per minute (Hignett & McAtamney, 2000; McAtamney & Corlett, 1993).

Recent studies on the predictive validity of these assessment tools indicate that both the ACGIH TLV for HAL and the SI are able to predict the risk of CTS (Garg et al., 2012), trigger digit (Kapellusch et al., 2014a), and lateral epicondylitis (Garg et al., 2013). In these studies, the individual risk factors aggregated to arrive at assessment scores were not directly evaluated. However, the predictive validity found for these tools suggests that forceful exertion, posture, repetition, or a combination of these are associated with DUE MSD health outcomes.

**Vibration, contact stress, and low temperature**

Exposure to hand-arm vibration (HAV) causes damage to tissue as energy is absorbed into the body (Jaffar et al., 2011). HAV can cause a worker to increase their exertion force to levels greater than normal levels by interfering with sensory feedback (Jaffar et al., 2011). Vibration is a risk factor for several specific

DUE MSDs such as Raynaud's disease. Several studies have noted that exposure to vibration increased worker risk of CTS (Bernard, 1997; Garg et al., 2012; Jaffar et al., 2011). Vibration as a risk factor is not directly included in the scope of the ACGIH TLV for HA, SI, RSI, REBA, or RULA.

Contact stresses are typically characterized as impingement by hard objects or surfaces and can result in tissue and nerve damage (Kolgiri et al., 2016). Ridges and edges on tools can result in contact stress to the hands while contact with work surfaces may put pressure on the forearm or wrist (Jaffar et al., 2011). Using parts of the body such as the hands, feet, or knees as a hammer or to hit objects can also be a form of contact stress (Jaffar et al., 2011). Of those assessed in the scope of this report, RULA and REBA are the only ergonomic assessment tools to account for contact stress. Contact stress is included in the Force/Loading Score of both assessments where a higher score is given to tasks where loading is repeated or shocks are present (ErgoPlus, n.d.).

Exposure to cold environments generally has a negative impact on performance and can increase the risk of injury or aggravating an existing condition (NIOSH, 2014) . Exposure to low temperatures reduces manual dexterity and can augment symptoms of nerve-end impairment (Jaffar et al., 2011). Like HAV, the ergonomic assessment tools evaluated in this report do not incorporate cold stress in their assessment but leave the interpretation of its effects to professional judgment of the evaluator(s).

**Duration of task per day**

The extent that the duration a task is performed per day affects the risk of DUE MSD development is not well researched (Garg et al., 2011, 2017). The general guidance for ergonomists and occupational safety and health (OSH) professionals has been that reducing the duration per day that workers are exposed to repetitive work would reduce their risk of developing an MSD (Killborn, 1994). There is a small amount of evidence that suggests an inverse relationship between increasing shift length and acceptable workload exists, but significantly elevated risk was not found in laboratory testing between groups exposed to biomechanical stressors for more than 8 hours per day (Garg et al., 2017). In the documentation for the RSI it is noted that the effect of duration per day is likely to be modified by the number of days per week a worker is exposed, their pattern of work-rest, and the nature of the task stressors (Garg et al., 2017).

The ACGIH TLV addresses task duration as a criterion for application of the tool. The TLV for HA applies to tasks that are performed for 4-8 hours per day (ACGIH, 2019); for duration beyond 8 hours professional judgement must be applied. The SI and RSI both include the variable "Duration of Task Per Day" which is measured in hours and ranges on an ordinal scale from <1 to >8 (Garg et al., 2017). The original SI set the multiplier for exposures >8 hours per day at 1.5 (Moore & Garg, 1995) while the RSI lowered the multiplier for the new maximum duration of 12 hours per day to 1.2 (Garg et al., 2017).

**Assessment tools**

The commonly used assessment tools overlap in their inclusion of force and repetition as risk factors, however they do not share the same variables for determining exertion intensity or the level of repetition (Bao et al., 2006; Garg et al., 2012;). As previously noted the ACGIH TLV for HA is determined using peak force and hand activity level while the SI includes two force related variables and three variables for repetition as well as a variable for the number of hours per day the task is performed. Generally, there is some overlap when assessment tools are compared and a moderate amount of agreement between tools like the SI and ACGIH TLV for HA have been found (Bao et al., 2006; Kapellusch et al., 2017). This has not been the case with the tools like RULA that placed more emphasis on hand/wrist posture alone (Drinkaus et al., 2003, Garg and Kapellusch, 2011). This has led to the interpretation that the tools may be measuring different aspects of exposure and each tool may be helpful in different situations or that a combination of the tools may predict risk more comprehensively (Kapellusch et al., 2017).

Research has been ongoing to validate the effectiveness of available assessment tools like the ACGIH TLV for HA, SI, and RULA. These studies have found mixed results for the ACGIH TLV for HA, good predictive validity for the SI, and low levels of agreement between the SI and RULA (Garg and Kapellusch, 2011). Additional epidemiologic research is a necessity to further understand which risk factors influence the development of DUE MSDs (Garg et al., 2011). This will provide a basis to modify and improve ergonomic assessment tools to increase predictive validity. Recent adjustments to existing assessment tools make further study a priority in order to understand how these modifications have affected the reliability of the tools.

# Chapter Three:

# Methods

The data for this study were obtained from a previous study on UAW-Ford manufacturing and assembling plants. About 50 jobs at each of four plants were targeted for review on the UAW-Ford Ergonomics Surveillance Tool (EST) decisions and experience with first time occupational visits (FTOVs) seeking treatment for MSD symptoms. The Ford medical database was analyzed to determine if DUE MSDs were recorded for each of the target jobs. Operators at each of the target jobs were interviewed and asked if they experienced any muscle or joint pain in the past month that they associate with that job and in which body region followed by questions to the specific region identified. An interview was considered positive for an MSD if there was interference with work, play, or sleep and treatment-seeking was from the clinic, from a private provider, or self-directed. The UAW-Ford EST variable data was used to gather information on the risk factors for each job with the raw EST data for each job included in the database. The established rules for reducing the data to EST decision was followed through several steps which reduce the raw data into exposure metrics. The risk factors analyzed included vibration, impulse rate, hand posture, and hand repetition.

Case status was assigned if an operator had sought treatment (FTOV), or if the symptom interview was positive. Non-cases were labeled such if neither an FTOV nor positive interview was associated with that job.

Based on the initial review of the data, the variables were coded to be dichotomous. Hand repetition was recoded so that scores of 1-2 were considered low exposure and 3-4 were high. Hand posture was recoded so that 0-2 were considered low and 3-5 were considered high. The presence of vibration and impulse was determined if a value greater than 0 was recorded in the EST data.

Statistical analysis was conducted using JMP 15 on a Mac computer. Logistic regression was used to test the relationship between vibration, impulse, hand repetition, and hand posture. Hand repetition and hand posture were initially tested as ordinal data with values from 1- 4 and 0-5 respectively. Vibration and impulse rate were tested as continuous variables.

Finally, because posture and repetition are well recognized risk factors for DUE MSDs, they were modeled together. The ACGIH TLV for Hand Activity provides a method to combine the two factors into one index value. The hand repetition score was translated from 1 to 5, to a Hand Activity Level (HAL) as 1, 3, 5, 7 and 9. The HAL value was used to calculate a normalized peak force ($NPF_{TLV}$) using equation 1. As forces were likely to be light, the posture score was translated directly to a normalized peak force (NPF). A peak force index ($PFI_{TLV}$) was then calculated using equation 2.

$$\text{Equation 1: } \mathrm{NPF}_{\mathrm{TLV}} = 5.6 - 0.56 * \mathrm{HAL}$$

$$\text{Equation 2: } \mathrm{PFI}_{\mathrm{TLV}} = \mathrm{NPF}/\mathrm{NPF}_{\mathrm{TLV}}$$

$PFI_{TLV}$ was modeled as a continuous variable and as a dichotomous variable where values less than or equal to 1 were considered below the TLV, and $PFI_{TLV}$ values greater than 1 were considered to be above the TLV. Logistic regression models were then applied to the dichotomous outcome for $PFI_{TLV}$ as well as a continuous variable with the presence or absence of impulse loading and vibration.

# Chapter Four:

# Results

A sample of Ford plants was selected by the UAW-Ford program staff to reflect the different kinds of work performed. The goal was to sample about 50 jobs within each plant. Table 1 reports the number of interviews and ESTs (job assessments) considered in the analysis of distal upper extremity disorders (DUEs).

Table 1. Number of interviews and ESTs linked by plant and overall

| Plant | Interviews | ESTs |
|---|---|---|
| BSP (stamping) | 50 | 48 |
| CEP (engine) | 57 | 52 |
| DTP (assembly) | 43 | 43 |
| KTP (assembly) | 59 | 59 |
| All | 209 | 202 |

First, the distribution of cases and non-cases for hand repetition score and hand posture score were examined (see Tables 2 and 3). For repetition, most of the cases were associated with a score of 3 or 4, so a dichotomous repetition outcome was based on 1 and 2 (low) versus 3 and 4 (high) as seen in Table 5. In a similar fashion for posture, a low score was 0, 1 and 2 and a high score was 3, 4, and 5 as seen in Table 4. For impulse rate and tool vibration, the dichotomous decision was absence or presence.

Table 2. Score versus DUE case status for hand repetition

| Repetition | Non-case | Case |
|---|---|---|
| 1 | 43 | 1 |
| 2 | 36 | 3 |
| 3 | 84 | 30 |
| 4 | 3 | 1 |

Table 3. Score versus DUE case status for hand posture

| Hand Posture | Non-case | Case |
|---|---|---|
| 0 | 2 | 0 |
| 1 | 4 | 0 |
| 2 | 9 | 0 |
| 3 | 138 | 26 |
| 4 | 12 | 7 |
| 5 | 1 | 2 |

The next step was to use the single dichotomous job risk factors (repetition, hand posture, impulse rate, and vibration) to tabulate the number of non-cases and cases for each factor, and then compute the sensitivity and specificity. The shaded data in Tables 2 and 3 were used to characterize the case data for repetition and posture, respectively. These are reported in the following tables. Table 4 is hand posture, where the sensitivity was very high with poor specificity. Table 5 is repetition with good sensitivity but weak specificity. Table 6 is presence of impulse loading with poor sensitivity but high specificity. Table 7 is vibration due to tools which displayed weak sensitivity and specificity.

Table 4. Posture Dichotomous

| Hand Posture | Non-case | Case | | Value | 95% CI |
|---|---|---|---|---|---|
| Low | 15 | 0 | Sensitivity | 1.00 | 0.90 to 1.00 |
| High | 151 | 35 | Specificity | 0.09 | 0.05 to 0.14 |

Table 5. Repetition Dichotomous

| Repetition | Non-case | Case | | Value | 95% CI |
|---|---|---|---|---|---|
| Low | 79 | 4 | Sensitivity | 0.88 | 0.73 to 0.97 |
| High | 87 | 31 | Specificity | 0.47 | 0.40 to 0.55 |

Table 6. Impulse Rate Dichotomous

| Impulse | Non-case | Case | | Value | 95% CI |
|---|---|---|---|---|---|
| Absent | 166 | 18 | Sensitivity | 0.48 | 0.31 to 0.66 |
| Present | 0 | 17 | Specificity | 1.00 | 0.98 to 1.00 |

Table 7. Vibration Dichotomous

| Vibration | Non-case | Case | | Value | 95% CI |
|---|---|---|---|---|---|
| Absent | 120 | 20 | Sensitivity | 0.42 | 0.26 to 0.61 |
| Present | 46 | 15 | Specificity | 0.72 | 0.65 to 0.79 |

Because the four job risk factors were ordinal and continuous, a logistic regression was run for all factors. Hand posture and impulse rate were both statistically significant at $p = 0.02$ and $p<0.01$ respectively. Repetition ($p = 0.13$) and vibration ($p = 0.95$) were not statistically significant. When modeled together, hand posture and impulse rate had a receiver operating characteristic (ROC) area under the curve (AUC) of 0.84, which represents some ability to discriminate between non-cases and cases.

The combination of hand posture and repetition is a well-known job risk factor. A logistic regression with both of these factors indicated that posture ($p = 0.02$) was significant, while repetition ($p = 0.13$) was not. The ACGIH TLV for Hand Activity provides a method to combine the two factors into one index value, $PFI_{TLV}$. This was modeled as a continuous and dichotomous variable where Below TLV represented $PFI_{TLV}$ values less than or equal to 1 and Above TLV represented values greater than 1. Table 8 is the resulting 2x2 table with sensitivity and specificity for the dichotomous analysis. The sensitivity was good, but the specificity was weak. For the logistic regression on $PFI_{TLV}$, the model was statistically significant at $p < 0.01$, with a ROC AUC = 0.73, which has modest ability to discriminate case status.

Table 8. $PFI_{TLV}$ Dichotomous

| $PFI_{TLV}$ | Non-case | Case | | Value | 95% CI |
|---|---|---|---|---|---|
| Below TLV | 79 | 4 | Sensitivity | 0.88 | 0.73 to 0.97 |
| Above TLV | 85 | 31 | Specificity | 0.48 | 0.40 to 0.56 |

The dichotomous versions of impulse rate, $PFI_{TLV}$, and vibration were modeled together. Presence of impulse ($p<0.01$) and $PFI_{TLV}$ ($p=0.01$) were significant while vibration ($p = 0.78$) was not. The ROC AUC when impulse presence and $PFI_{TLV}$ were modeled together was 0.85, which represents good ability to discriminate cases and non-cases.

## Chapter Five:

## Discussion

Force, hand posture, and repetition are well documented risk factors for MSDs. There is also some evidence that vibration, contact stress, low temperatures, and shift length impact health outcomes. The degree to which these factors play a role is not completely clear and is reflected by the difference in emphasis or inclusion of these risk factors in ergonomic risk assessment tools. While the major tools do have their differences, they all include some measure of force, hand/wrist posture, and repetitiveness. The UAW-Ford EST collects information on the majority of commonly accepted risk factors with the exception of exertion force and temperature.

Data from approximately 200 jobs from four plants were analyzed. Initially the distribution of cases and non-cases for hand repetition score and hand posture score were examined. It was observed that most of the cases were associated with a repetition scores of equal to or greater than 3. A score of three represented exposures with a “normal” speed of motion with sustainable pace, while a score of 4 indicated jobs with rapid motion and limited opportunity for rest. In a similar fashion for hand posture, cases were associated with moderate posture deviation represented by scores at or above 3. This led to the decision to dichotomize posture and repetition into high and low exposure categories. For impulse rate and tool vibration, the dichotomous decision was based on absence or presence. A $PFI_{TLV}$ was estimated under the assumptions that NPF was low and could be estimated using hand posture, and that repetition could be adjusted to estimate a HAL.

Analysis of the UAW-Ford EST data indicates that hand posture and impulse rate were significantly associated with FTOVs and DUE MSD symptoms. Hand posture had the highest sensitivity, indicating that jobs with poor/awkward hand postures carry more risk. However, it also had poor specificity as the majority of non-case jobs were also exposed to moderately awkward posture. This may indicate that an interaction with another risk factor occurred or that personal risk factors had a role in the case outcome. The opposite was true for impulse rate which had strong specificity and weak sensitivity. All of the non-cases occurred when impulse was absent, but so did slightly more than half of the recorded cases. The presence of impulses is not specifically addressed in most research, but as used by EST impulses included both mechanical stress and jerking motions from tools. When posture and the presence of impulse were modeled together the ROC AUC was 0.84 indicating that in combination these variables have a fair ability to discern which jobs will have elevated risk.

Repetition was not a statistically significant factor but was transformed into an estimated HAL. HAL was included with hand posture, which was used in place of NPF, in the $PFI_{TLV}$. The estimated $PFI_{TLV}$ was a statistically significant predictor. This is supported in much of the literature where combinations of risk factors appear to increase DUE MSD risk. There was a marginal increase in ROC AUC when $PFI_{TLV}$ and the presence of impulse were modeled together. The use of hand posture in place of NPF could simplify the assessment process and reduce the assessment variability associated with observers assessing exertion force.

Vibration was the only risk factor that was not statistically significant in any of the logistic regression models. This may be due to the nature of the risk factors present in the jobs. The effect of vibration may be related to exertion force which was assumed to be low in the tasks analyzed.

## Chapter Six:

## Conclusion

This study examined the use of hand posture, repetition, impulse rate, and vibration by the UAW-Ford EST to assess DUE MSDs. Analysis of UAW-Ford EST data indicated that the presence of moderate to severe deviation in hand posture and impulse loading can be used to predict the development of DUE MSDs. Hand posture had high sensitivity with weak specificity while the presence of impulse loading showed weak sensitivity and good specificity. When used together to predict risk, these factors were able to distinguish between cases and non-cases well.

A method for repurposing hand posture and repetition into NPF and HAL to estimate $PFI_{TLV}$ was also tested and determined to be predictive with good sensitivity and weak specificity. Using the $PFI_{TLV}$ above 1 as a reference value for hazardous exposure coupled with the presence of impulse loading yielded an ability to identify cases from non-cases similar to that of using hand posture with impulse loading. Exposure to high repetition or the presence of vibration were not found to be predictive of DUE MSD risk.

Efforts should be made to reduce impulse loading and poor hand postures in automotive manufacturing jobs. Analysis of UAW-Ford EST data suggests that minimizing the impulse rate experienced during tasks and improving the hand postures in which work occurs will reduce the risk of DUE MSDs.

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**Appendices**

## Appendix A: UAW-Ford Symptom Interview Form

UAW-Ford Symptoms Interview
Version 2.0

| | |
|---|---|
| USF Job Code | |
| Job / Workstation Description | |
| Location | |
| Interviewer | |
| Date | |

| | |
|---|---|
| Was permission given to proceed with the interview? | YES -- Continue<br>NO -- Stop |
| Have you worked at this workstation for more than a month? | YES -- Continue<br>NO -- Stop |
| Have you had any muscle or joint pain or discomfort associated with this job in the past month? | YES -- Continue<br>NO -- Stop |

| In what body region is/was the pain or discomfort most severe?<br>Is/Was there pain or discomfort in other regions (if so, which ones)? | P—Primary<br>O—Other |
|---|---|
| Neck or Shoulders | |
| Hands, Wrists or Elbows | |
| Low Back | |
| Other (specify): | |

| For the most severe pain or discomfort | Y—Yes<br>N—No |
|---|---|
| Did the pain or discomfort interfere with your ability to do your job? | |
| Did the pain or discomfort interfere with your outside activities? | |
| Did the pain or discomfort interfere with your sleep? | |
| | |
| Did you seek treatment from the plant clinic? | |
| Did you seek treatment from a personal or private health care provider? | |
| Did you use non-prescription drugs, hot or cold compresses, or time off for recovery (sick leave or vacation)? | |
| Did you do anything else for relief? (Specify) | |

| For the other pain or discomfort | Y—Yes<br>N—No |
|---|---|
| Did the pain or discomfort interfere with your ability to do your job? | |
| Did the pain or discomfort interfere with your outside activities? | |
| Did the pain or discomfort interfere with your sleep? | |
| | |
| Did you seek treatment from the plant clinic? | |
| Did you seek treatment from a personal or private health care provider? | |
| Did you use non-prescription drugs, hot or cold compresses, or take time off for recovery (sick leave or vacation)? | |
| Did you do anything else for relief? (Specify) | |

## Appendix B: University of South Florida IRB Approval Letter

UNIVERSITY of SOUTH FLORIDA

NOT HUMAN SUBJECTS RESEARCH DETERMINATION

June 2, 2020

Zachariah Brandes-Powell
12874 Palm Drive
Largo, FL 33774

Dear Mr. Zachariah Brandes-Powell:

On 6/2/2020, the IRB reviewed the following protocol:

| | |
|---|---|
| IRB ID: | STUDY001029 |
| Title: | Assessment of the Effectiveness of UAW-Ford Ergonomic Assessment Tool (EST) for the Analysis of Distal Upper Extremity Musculoskeletal Disorders (DUEMSDs) |

The IRB determined that the proposed activity does not constitute research involving human subjects as defined by DHHS and FDA regulations.

IRB review and approval is not required. This determination applies only to the activities described in the IRB submission. If changes are made and there are questions about whether these activities constitute human subjects research, please submit a new application to the IRB for a determination.

While not requiring IRB approval and oversight, your project activities should be conducted in a manner that is consistent with the ethical principles of your profession. If this project is program evaluation or quality improvement, do not refer to the project as research and do not include the assigned IRB ID or IRB contact information in the consent document or any resulting publications or presentations.

Sincerely,

Jennifer Walker
IRB Research Compliance Administrator

**Institutional Review Boards / Research Integrity & Compliance**
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Page 1 of 1