THE DEVELOPMENT OF AN INDEX FOR THE PROXIMAL UPPER EXTREMITY

A Dissertation

by

ERIN KURUSZ WALLINE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2005

Major Subject: Interdisciplinary Engineering

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ABSTRACT

The Development of an Index for the Proximal Upper Extremity. (May 2005)

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Analysis techniques specific to the proximal upper extremity have historically been overlooked in the field of ergonomics. This research effort provides a methodology that will allow the ergonomics practitioner to analyze a job and predict whether or not that job exposes workers to increased risk of proximal upper extremity disorders. Literature from the fields of physiology, biomechanics, and epidemiology was assimilated in order to understand the theories of pathogenesis of disorders in the rotator cuff and to identify the risk factors associated with proximal upper extremity disorders. A retrospective epidemiological study was conducted to identify job task variables that may contribute to the occurrence of proximal upper extremity disorders. Two proximal upper extremity constructs were proposed: a fatigue-based model and a compressive load-based model. The constructs incorporated lessons learned from the literature and results from the epidemiological study. Validation of the models was performed using data from the epidemiological study. It was determined that the fatigue-based model was a good predictor of proximal upper extremity disorders.

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CHAPTER I

INTRODUCTION

An enduring problem in occupational medicine is the occurrence of upper extremity injuries and disorders. Proximal upper extremity (PUE) disorders are particularly important because of the impact on a person's work capabilities and quality of life. Work that would normally be performed primarily using the distal upper extremity (DUE) could be hindered by PUE problems if the tasks involved reaching or the use of a heavy tool that could create a static load on the shoulder. PUE conditions may not necessarily occur in the context of work. The reported prevalence of PUE disorders ranged from 13% to 37% in cadaver populations, while self-reported PUE symptoms ranged from 6% to 34% in the general population (Keyes 1935; Wilson 1943; DePalma et al. 1950; Harmon 1958; Cotton and Rideout 1964; Westerling and Jonsson 1980; Takala et al 1982; Anderson 1984; Cunningham and Kelsey 1984; Bergenudd et al 1988; Van der Windt et al 1995). Bilateral rotator cuff tendon ruptures have been observed in cadaver studies 50% to 87% of the time (Wilson 1943; Wilson and Duff 1943; Cotton and Rideout 1964; Petersson 1983). The PUE might include the scapulothoracic (SC), acromioclavicular (AC), and glenohumeral (GH) joints. This research will encompass only disorders of the glenohumeral joint, excluding the trapezius.

The impact of PUE disorders and injuries is extensive. In an account of the frequency, impact and cost of upper extremity injuries in the working population, Kelsey (1997) reported that the shoulder and upper arm have an estimated average annual incidence of 650,000 sprain or strain injuries that result in a visit to a health care practitioner or restricted activity, leading to approximately 1,450,000 days lost from work and 2,387,000 restricted activity days. According to data from the U.S. Bureau of Labor and Statistics (BLS), in the year 2001 the rate of shoulder injuries and illnesses per 10,000 full-time workers was 9.7 (BLS, 2001).

This dissertation follows the style and format of *Ergonomics*.

BLS data also indicated that greater than 90,000 shoulder or upper arm injury and illness cases were reported across all private industry in 2001, with a reported 12 median days away from work (BLS, 2001).

One of the objectives of this research effort is to develop a methodology that will allow an ergonomics practitioner to analyze a job and predict whether or not that job exposes workers performing it to an increased risk of PUE disorders. That is, a baseline risk for PUE disorders exists in the adult population, but there is a need to develop a methodology to determine whether a person's occupation increases their risk. Another objective is assimilation of the research literature involving the PUE. Fields of research, such as physiology, biomechanics, and epidemiology all contain relevant information and authors range from medical doctors, ergonomists, industrial engineers, or other health care practitioners, to name a few. There has not yet been a concerted effort by any of the aforementioned fields to incorporate much, if any, research from related fields. This has led to a disjointed, but progressively growing body of knowledge on the PUE disorders and the implications of work-relatedness. In fact, the assimilation of the tremendous bodies of work in these fields has been a crucial step in the methodology development process; lengthy, but necessary. It is hoped that this particular research effort will provide a foundation for subsequent studies and other research efforts involving the PUE.

The spectrum of PUE disorders ranges from degeneration in the form of calcific deposits; collagen fascicle separation or rigidity; tendon or bursa thickening or disorganization; and increased proliferation of blood vessels (vascularized granulation tissue); to partial or full rotator cuff tears, sometimes accompanied by torn muscle fibers or bone fragment loss. Though opinions regarding clinical signs of PUE degeneration and disorders are not usually debated, theories of the pathogenesis of PUE disorders vary in the medical community. Some purport that rotator cuff tendon degeneration is caused by gradual wear and tear, while others believe that a mechanical source perpetrates the degeneration. Both theories will be discussed and evaluated.

Proximal Upper Extremity Anatomy and Function

Nixon and DiStefano (1975) provided a clear synopsis of the anatomy of the shoulder joint. The superior portion of the shoulder joint consists of the coracoacromial arch and directly below, the subacromial bursa. Continuing inferiorly, the supraspinatus tendon lies beneath the bursa. The inferior portion of the supraspinatus tendon is bordered by a synovial cavity and the head of the humerus. The infraspinatus and teres minor tendons pass through the same region as the supraspinatus tendon, and all tend to fuse together, forming a large posterior musculotendinous surface area. The tendon of the subscapularis inserts on the anterior portion of the joint.

Inman et al (1944) investigated the function of the shoulder joint. The authors noted that use of the term "shoulder joint" is misleading since four joints contribute simultaneously to the movement at the shoulder: the sternoclavicular, acromioclavicular, glenohumeral, and scapulothoracic joints. Scapulohumeral muscle groups were defined as those passing from the scapula to the humerus, and included the supraspinatus, infraspinatus, teres minor, subscapularis, deltoid, and teres major. The authors found that in the first 30° to 60° of upper arm elevation, the scapula seeks stability in relation to the humerus. In this early phase of elevation, (termed "the setting phase"), the scapula may remain fixed or move medially or laterally. Movement in the setting phase is individual and unpredictable. Elevation beyond the setting phase is approximately a 2:1 ratio of humeral to scapular motion; for example, for every 15° of upper arm elevation, the glenohumeral joint contributes 10° and the rotation of the scapula contributes 5°. Other researchers have corroborated the approximate ratio of humeral to scapular motion (Reid 1969, Doody et al 1970, Lucas 1973), though a 3:2 ratio has also been proposed (Freedman and Munro 1966).

Inman et al. generated a curve representing the force requirements for elevation of the arm between 30° and 180°. The peak elevation force requirements occurred at 90° and fell to zero at 180° of elevation, which is the vertical arm position above the head. The resultant force (representing the active force in the form of downward pull of the infraspinatus muscle and the passive resistance of pressure and friction) peaks at 60°, and after 90°, rapidly falls to zero at 135°. Using intramuscular wire EMG, the authors showed that the activity in the supraspinatus peaked between 100° - 110° abduction and 90° flexion. Other investigators concurred with these ranges of peak supraspinatus activity (Reid 1969, Lucas 1973). Other primary muscles of the rotator cuff demonstrate peak activity at elevation angles greater than 120° (Inman et al 1944, Reid 1969).

Pathogenesis of Tendon Disorders in the Rotator Cuff

Pathogenesis of Tendon Rupture

Various investigators have performed studies on human and animal cadaver muscle-tendon-bone systems. Though these efforts were not necessarily specific to the PUE, the lessons learned apply to any muscle-tendon-bone system. The most common cause of subcutaneous tendon rupture is compression, though tension may also preface rupture (McMaster 1933). Mechanical stress or strain, such as lateral pressure, does not necessarily injure a tendon (McMaster 1933, Macnab 1973). When a tendon does rupture, it ruptures at the site of induced injury or compressive load (McMaster 1933, Macnab 1973), regardless of load rate (Welsh and Macnab 1971). An analogy can be found in the anatomical placement of the supraspinatus tendon over the head of the humerus. The humerus displaces the tendon laterally and increases stress at the point of insertion, which is the most common rupture site. Lindblom (1939) demonstrated that strain applied at right angles to the tendon insertion could produce a rupture in the tendon tissue.

If a defect (such as a small tear) was introduced in the tendon, elongation of the tendon would widen the defect until the width of the tendon at the site of the defect was about half its normal dimension; rupture would occur at the site of the enlarged defect (Macnab 1973, Welsh and Macnab 1971). Rupture occurred at much lower loads at sites with degeneration present in comparison to sites without degeneration (Macnab 1973). Rate of tendon load does not affect rupture *site*; however, the more rapid the loading, the stronger the tendon-bone junction because the tendon is stiffer under more rapid load

(Welsh and Macnab 1971). To make a work analogy, lifting or moving a heavy load happens more effectively with an abrupt exertion rather than expending the same amount of energy over a longer time period.

Clinical Observations on Proximal Upper Extremity Disorder Etiology

The Relationship between Degeneration and Rupture

With rare exception (Codman 1938, Lindblom 1939), investigators have reported that degeneration occurs prior to non-acute rotator cuff tendon rupture (Meyer 1937, Howard 1941, Wilson and Duff 1943, DePalma et al. 1950, Coventry 1953, Harmon 1958, Moseley and Goldie 1963, Owen 1969, Petersson 1983, Uhthoff and Sarkar 1990). Rotator cuff tendon rupture has been frequently found to be bilateral (Wilson 1943, Wilson and Duff 1943, Cotton and Rideout 1964, Petersson 1983), suggesting that rupture is not necessarily use-related, and implying that degeneration precedes rupture. Rupture of the supraspinatus tendon typically occurs as a transverse tear (indicating traumatic rupture) in the tendon fibers within a half inch from the point of insertion (Wilson 1943).

Additional usage factors or individual risk factors may explain asymmetric rupture. Wilson and Duff (1943) noted that among autopsy specimens, in every instance of unilateral full rupture, the circumference of the arm at the level of the biceps belly was at least one centimeter larger on the rupture side compared to the other side, indicating that rupture occurred on the dominant arm. Owen (1969) postulated that any activity requiring repetitive arm abduction, especially with internal arm rotation, may accelerate the degenerative process. Other investigators have also postulated the relevance of repetitive arm abduction or flexion with or without rotation (Meyer 1937, Bywaters 1979, Petersson and Gentz 1983).

Wilson and Duff (1943) also observed that once adult age was reached, the length of the supraspinatus tendon did not increase with age progression, and noted that a normal supraspinatus tendon is about 2.25 centimeters long. However, Petersson (1984) found that the length of the supraspinatus tendon increased with age, as did tendons that had undergone a tear. The number of arterioles in the tendons of the shoulder joint was found to decrease with age, and their presence was rare in normal tendon material after the age of forty years. Increased levels of degenerative changes were found with increased age, and the magnitude of degenerative changes was observed to be greater among those specimens with a work history of heavy manual labor. Other investigators have also found increased degeneration with advanced age (DePalma et al. 1950, Owen 1969, Bywaters 1979, Petersson 1983, Uhthoff and Sarkar 1990). Howard (1941) purported that an ischemic tendon loses no length, yet diminishes in diameter. Howard theorized that endothelial cells bathe the tendon in plasma, thus maintaining tendon lubrication and pliability, while neglecting nourishment and metabolic waste removal that a non-ischemic system would provide. Wilson (1943) noted that if the tear occurs on the joint side, tendon lengthening occurs, whereas if the tear occurs on the side of the subacromial bursa, tendon fiber fibrillation (spontaneously occurring fiber contractions) occurs. Wilson believed that rupture of a healthy tendon does not occur and that only a degenerated tendon would rupture with force.

Effects of Avascularity in the Rotator Cuff

Vascularity is essential for repair of damaged soft tissues. Peacock (1957) demonstrated the importance of blood supply with regard to surgical tendon repair. The tendon receives blood from arteries expressly for the tendon from muscular and osseous vessels. As an additional source, longitudinal intratendinous vessels are present. When just one of the three blood sources for the tendon is inhibited or occluded, blood flow within the tendon is minimal or nonexistent. Niepel and Sitaj (1979) concluded that a working muscle appropriates most of the blood at the expense of the tendon and enthesis (the anatomical insertion of tendon and ligament into bone). The tendon, however, is a resilient structure. Rupture does not occur without duress. McMaster (1933) demonstrated that when blood supply to the tendon was arrested, stress led to tendon rupture. When blood supply was unobstructed, the tendon did not rupture under load. External pressure on a blood vessel causes a reduction in the diameter of the vessel and a decrease in blood flow, the relationship between which is not necessarily linear; factors such as tension, edema, or other factors may influence the relationship (Ashton 1975).

In certain regions of the tendons in the rotator cuff, areas of relative avascularity are present. An avascular region is one in which blood flow is compromised or nonexistent. Several authors have documented the presence of these avascular regions in the rotator cuff (Codman 1937, Lindblom 1939, Moseley and Goldie 1963, Rothman and Parke 1965, Rathbun and Macnab 1970, Macnab 1973). In an investigation to evaluate the importance of vascularity in the rotator cuff with regard to the occurrence of calcium deposits and ruptures, Moseley and Goldie (1963) attempted to identify whether a change in vascularity could explain the pathological changes that predispose a tendon to rupture. The authors sought to study the pattern of vascularity in the “critical zone,” located one centimeter medial to the insertion of the supraspinatus tendon. The critical zone was characterized as a region with tendencies to develop calcium deposits and comprise ruptures. In addition, the critical zone contained anastomoses (irregular spacing) between vessels originating from the bone at the point of insertion, and the longitudinal vessels evolving from the muscle.

Moseley and Goldie (1963) found no differences in vascular patterns between genders or among ages. Other authors have also concluded that vascular patterns are not altered with progressing age (Senior 1924, Trueta and Harrison 1953, Rathbun and Macnab 1970). However, though the vascular *patterns* of the rotator cuff did not vary among ages, the vessels appeared thinner in older cadavers, which may explain why, clinically, degenerative changes are more frequently seen with advancing age.

The results from Moseley and Goldie (1963) also confirmed an obstruction of the vessels penetrating the supraspinatus tendon from the humeral head. The vessels that emerge from the humeral head fan out and end abruptly in the tendon, leaving a zone devoid of *filled* vessels. The authors concluded that the critical zone, or, the area prone to degenerative changes, is not less vascularized than other parts of the rotator cuff. That is, vessels in the critical zone are not fewer in number or smaller in diameter, but because of the anastomotic network of osseous and tendinous vessels, flow throughout the critical zone may be inhibited. Similar results were obtained regarding the zone of avascularity by other investigators (Rothman and Parke 1965, Rathbun and Macnab 1970).

Rathbun and Macnab (1970) described rotator cuff tendons as flat, with vessels coursing longitudinally through the length of the tendon, with the exception of a few vertical vessels. They theorized that the longitudinal nature of the rotator cuff vessels makes them susceptible to pressure from the humeral head. To investigate that theory, infusions were performed in cadaver shoulders with the arm passively abducted, thus relaxing the supraspinatus tendon. The results demonstrated almost completely filled vessels throughout the tendon to the point of insertion, which indicated that the level of tension in the tendon is central to blood flow. The supraspinatus tendon has to pass over the swell of the head of the humerus in order to arrive at its insertion point. The constant pressure from the humeral head while the arm is adducted with neutral rotation (resting position of arm) may “wring out” the vessels in that area.

Rathbun and Macnab (1970) noted that the zone of relative avascularity in the supraspinatus tendon is the most prominent location of breakdowns including tendinitis, calcification, and spontaneous ruptures. It was concluded that the avascular zone precedes degeneration, and is not a result of it. The authors acquiesced that decreased blood supply may not be the sole cause of degenerative changes. As degeneration in the tendons advances, the tendon attenuates and becomes more avascular. In all instances of tendon rupture in this study, the majority of the tendon proximal to the rupture was avascular and showed degenerative changes.

Macnab (1973) postulated that degenerative changes originating in the supraspinatus tendon may spread to other, well-vascularized tendons throughout the shoulder capsule, producing capsulitis. Under the assumption that initial degeneration is due to cell death because of avascularity, an experiment was constructed to trace the histological changes that lead to capsulitis. From experiments with rabbit tendons simulating the supraspinatus tendon passing over the humeral head, it was noted that areas of disorganization in the center of the tendon were surrounded by healthy fibers.

The healthy area contained a large amount of round cells. It was unknown whether the presence of the cells were a result of response to the degeneration or whether cell presence was a histological change that occurred due to imminent tendon breakdown. To investigate this observation, an avascular tendon fragment was implanted into a healthy rabbit tendon. The avascular portion was subsequently surrounded by round cells in the healthy sections. Testing indicated that the round cells were from the lymphatic system, which suggested an immune response. When the respective lymph node was removed and an avascular tendon fragment was implanted, no round cell infiltration was observed, and the implanted tendon assimilated without evoking distress.

Macnab (1973) extended the research on rotator cuff vascularity by experimentally introducing interference with blood supply to the tendons. An attempt was made to correlate histological changes with clinical diagnoses associated with rotator cuff tendinitis. In a normal tendon, the characteristic pattern of collagen fascicles is wavy, which Macnab postulated is a trait that probably supports elasticity of the tendon. Tenocytes (flat tapered cells sparingly distributed among collagen fibrils) are ordinarily spaced evenly throughout the fascicle network. When collagen fascicles separate, which is an early sign of degeneration, the tenocytes move into the broader spaces and become plumper. As degenerative changes progress, the collagen fascicles continue to separate and eventually fragment, disallowing straightforward reconstitution of their natural arrangement.

Macnab (1973) performed an experiment with a rabbit tendon which demonstrated the effects of avascularity on collagen fascicle structure. The Achilles tendon of a rabbit was modified such that blood flow was extinguished. Similar histological changes were observed: collagen fascicles separated, tenocytes subsided into larger interfascicular spaces, and fragmentation of the collagen fascicles commenced. Thus, complete lack of blood flow through the rabbit tendon produced similar histological changes to those seen in rotator cuff degeneration. An experiment was constructed to reproduce the partially compromised blood flow in the supraspinatus tendon as it passes over the humeral head by positioning a plastic mound under the rabbit tendon. Histological changes that occurred in the rabbit tendon were sequentially equal to the pattern of changes that occurred in the rotator cuff tendons of human cadavers. Disorganization began in the center of the tendon and eventually reached the outer portions of the tendon. A similar pattern of disorganization was also seen by Cotton and Rideout (1964). This observation was evidence against the speculation that mechanical friction of the supraspinatus tendon against the coracoacromial ligament is the cause of degenerative changes, since changes under an impingement supposition would begin superficially and move inward. In fact, Macnab asserted that the supraspinatus tendon does not impinge against the coracoacromial ligament unless the tendon is already partially torn and buckles at the site of the tear upon abduction. As will be discussed, proponents of the mechanical impingement theory would disagree.

In view of the evidence from experimental studies, Macnab (1973) constructed a hypothesis. The anatomical disposition of the supraspinatus tendon creates a zone of relative avascularity near the tendon’s insertion point. Cells in the tendon rely on blood supply for survival. As age progresses, diffusion of blood through the zone of relative avascularity may become more difficult and sections of the tendon may die. Inflammation of the tendon (tendinitis) may occur because of cell death, and is potentially followed by inflammation of the bursa (bursitis) or calcium deposition in the bursa (calcific bursitis) or tendon.

Mechanical Impingement

Neer (1972) agreed with the proposition that the supraspinatus tendon, and at times, the anterior portion of the infraspinatus tendon and the long head of the biceps tendon, were the primary sites of degenerative tendinitis and rupture, but claimed that enough emphasis was not placed on the fact that those structures are located anterior to the acromion. Elevation (abduction or flexion) of the arm while internally or externally rotated impinges the critical zone of the supraspinatus tendon under the anterior acromion process. The impingement occurs at an elevation of approximately 80° elevation of the arm. Below 80° of elevation, the greater tuberosity of the humeral head is not in immediate contact with the acromion process or the coracoacromial ligament. Above 80° of elevation, the humeral head is transferred down and away from the acromion and the coracoacromial ligament, eradicating any contact stress.

Through surgical response to decompress the rotator cuff from impingement and repair tears in the rotator cuff, Neer (1983) substantiated evidence for his impingement postulates. Neer judged impingement, rather than circulatory impairment, to be responsible for 95% of rotator cuff tears, and believed impingement to occur in three progressive stages. Stage I included edema and hemorrhage, and was thought to result from excessive overhead work. Stage II, thickening of the bursa or tendinitis, was thought to be a result of multiple episodes of mechanical inflammation. Stage III included tendon rupture and bone spurs, which were postulated to be the result of continued impingement wear. Possible bone changes included a slight prominence on the greater tuberosity at the supraspinatus tendon insertion point or a traction spur on the anterior acromion inside the coracoacromial ligament. Neer noted that Stage III impingement occurred almost exclusively in patients over forty years of age.

Neer acknowledged that trauma, though it has the potential to enlarge a tear, rarely appears to be the principal cause of the tear. Approximately 50% of Neer’s patients had no recollection of a specific injury that caused their rotator cuff tear. In those patients who did recall an injury, the majority recalled a history of intermittent shoulder pain prior to the injury, which Neer claimed was evidence that impingement wear preceded the tear. Several other authors reported the possibility of mechanical impingement playing a role in rotator cuff tendon disorders (Martin 1940, Wilson 1943, Simmonds 1949, DePalma et al. 1950, Cotton and Rideout 1964, Booth and Marvel 1975, Simon 1975, Bywaters 1979, Petersson and Gentz 1983, Uhthoff and Sarkar 1990, Bigliani et al 1991, Fu et al 1991).

Anatomical differences among people may also explain why some experience rotator cuff tears and others do not. Neer proposed that variations in the shape and slope of the acromion may explain a person’s susceptibility to impingement problems. An acromion with a pronounced anterior edge on its undersurface, as well as a lesser slope would predispose a person to impingement problems. Other investigators have also proposed that anatomical abnormalities may affect the potential for impingement of the rotator cuff tendons (Uhthoff and Sarkar 1990, Bigliani et al 1991).

The research conducted by Neer generated a differing theory of supraspinatus tendon disorder pathogenesis. Elevation of the arm through approximately 80° abduction or flexion impinges the supraspinatus tendon under the anterior acromion process. Bone spurs were said to be a Stage III manifestation of this mechanical contact stress; however, it was noted that spurs were found primarily in patients over 40 years old. By his own theory, a person could manifest Stage III symptoms based on the occurrence of the mechanical impingement process (elevation of the arm through 80°), regardless of age. The importance of abnormal acromion size or shape was noted as a possible effector of supraspinatus tendon impingement.

Summary

There were several lessons learned from the research on the pathogenesis of tendon rupture. The tendon is resistant to rupture through tensile loading, but is susceptible via compressive loading (non-parallel strain). Rupture did not occur when blood flow was unobstructed. Tendon rupture will occur at a defect or at a site of compression; however, in the absence of a defect or compression site, rupture will occur at the point of insertion. A more rapid load rate is protective if no defect is present. Once a defect such as a small tear is present, it can promulgate freely through the tendon, especially under a high load rate.

Investigations on rotator cuff degeneration and rupture in cadaver populations provided valuable insights into the behavior of the tendons under duress. It is widely accepted that degeneration occurs prior to rupture, and that both tendon degeneration and tendon rupture are more frequently found with advancing age. Additionally, the number of arterioles (small blood vessels) in the tendons of the rotator cuff diminishes with age; as they diminish in number, so does blood supply to the region. Because of this, there is a natural increase in ischemia with advancing age. Tendon degeneration begins internally and moves outward. Degeneration is often accompanied by proliferation of blood vessels around the degenerated regions, perhaps as a response to heal the offending tissue. Tendons with degeneration present will rupture at lower loads than healthy tendons, as degeneration has been demonstrated to weaken the tendon.

The experimental studies of vascularity in the rotator cuff generated several key findings. Avascular zones are the most frequent sites of tendinitis, calcification, and rupture. There exists a zone of avascularity near the insertion of the supraspinatus tendon where blood vessels exist but are not sufficiently filled, in part because of irregularly-spaced vessels. A partially abducted arm, which relaxes the supraspinatus tendon, allows for better fill of the vessels. This demonstrates that tension is proportional to blood flow. The longitudinal vessels in the supraspinatus tendon are particularly susceptible to pressure. Older specimens demonstrated less blood flow through the same network of vessels compared to younger specimens. Decreased blood supply leads to an increase in degeneration, which begins centrally in the tendon and moves outward. Increased external tendon pressure decreases blood vessel diameter, hence decreasing perfusion, which is particularly perilous in avascular areas.

Researchers have also suggested that supraspinatus tendon impingement may occur via the coracoacromial arch, the acromion itself, abnormal subacromial bursa growth, or abnormal bone spurs or shape, and can be aggravated by calcium deposits and tendon tension. Accumulated degeneration in the rotator cuff tendons in conjunction with some form of compressive load could produce a more probable rupture site.

If peak load plays a role in the development of proximal upper extremity disorders, it may, in part, explain why disorders of the supraspinatus tendon are more common than other rotator cuff tendon disorders; that is, tasks that require work with the arms elevated greater than 120° are not as customary as those that require lesser elevation angles.

CHAPTER II
EXPERIMENTAL RESEARCH ON THE PROXIMAL UPPER EXTREMITY

General Muscle Fatigue Principles

Research conducted by Rohmert (1960, 1962) on static muscular activity resulted in concepts that have been referenced numerous times across many bodies of literature since its initial publication. Rohmert maintained that tiring static muscular work begins with holding forces greater than 15% MVC, which he called the endurance limit (EL). Greater reduction in maximum strength occurred with greater duration of static muscular work above the EL. An increased reduction in maximum strength occurred with previous heavy work above the EL. No differences were found with different muscle groups or between workers. Recovery was dependent on the degree of fatigue; that is, regaining the equivalent decrease in maximum strength took the same amount of recovery time. Rohmert (1973) later asserted that fatigue and recovery are periodic processes in every living organism. As such, fatigue should not be considered a harmful process, because, while inorganic material fatigue (as in deterioration of material due to periodic mechanical stress) is irreversible, biological fatigue is reversible. Rohmert emphasized that the definitions of fatigue and recovery should be dependent on each other. He defined fatigue in the following way: “Reduction of the functional capacity of an organ or of the organism as a result of action; fatigue is eliminated by recovery, fatigue and recovery being understood as time processes. The state caused by tiring can be measured as a degree of fatigue. Fatigue increases the degree of fatigue, recovery reduces it.”

Jonsson (1978) challenged Rohmert’s postulated endurance limit, below which static loads could theoretically be maintained. Instead, Jonsson recommended limits of acceptable muscular load based on studies of muscular endurance during constrained static and dynamic work. For constrained work with a duration of one hour or more, the author recommended: (1) that static load should not exceed 2% MVC, and must not exceed 5% MVC, (2) that the median load level should not exceed 10% MVC, and must not exceed 14% MVC, and (3) that the peak load should not exceed 50% MVC, and must not exceed 70% MVC. Jorgensen et al (1988) also concluded that indefinite endurance times below 15 - 20% MVC could not be maintained without a disruption in the homeostasis of the working muscles. Study results demonstrated that muscle fatigue may occur with one-hour sustained isometric contractions at 5 – 10% MVC.

Use of Electromyography or Ratings of Perceived Exertion as Predictors of Force

The relationships between subjective, objective, and physiological aspects of fatigue were evaluated in some studies from which a few key insights could be gleaned (Lloyd et al 1970, Cooper et al 1979, Dul et al 1991, Grant et al 1994). Physiological signs of fatigue have been shown to occur prior to a person's endurance limit or feelings of pain (Lloyd et al 1970, Kadefors et al 1978). High correlation exists between perceived exertion and produced force, regardless of whether force is high or low; that is, a linear relationship between perception of exertion and force exists (Cooper et al 1979, Oberg et al 1994). Correlation exists between ratings of perceived exertion (RPE) and muscle fatigue (Dul et al 1991). Both RPE and readings of electromyography (EMG) are similarly related to muscle force, though RPE is a somewhat better predictor of force in complex tasks, while EMG more accurately represents force in static tasks or at lower contraction levels (Lind and Petrofsky 1979, Grant et al 1994). Other investigators have found (under isometric static conditions) that intramuscular pressure (IMP) and EMG are both good estimators of muscular force (Korner et al 1984).

Other researchers evaluated the reliability of electromyography as a representation of force. Some have found that the relationship between EMG and force is linear (Bouisset and Goubel 1973). Others have suggested that the relationship is approximately linear at lower percent maximum voluntary contractions (%MVCs), then becomes exponential at higher %MVCs (Antti 1977). Some have found a curved relationship at lower %MVCs and an approximately linear relationship at higher %MVCs (Woods and Bigland-Ritchie 1983). Physiological factors such as intramuscular pressure, joint angle, the number or rate of muscle motor units firing, or the organization of motor units have been theorized to affect the relationship (Bouisset and Goubel 1973, Woods and Bigland-Ritchie 1983, Korner et al 1984, Jarvholm et al 1988a, Jarvholm et al 1988b, Westgaard 1988, Jarvholm et al 1991a, Jarvholm et al 1991b, Solomonow et al 1991).

Upper Arm Elevation and Its Impact on Proximal Upper Extremity Muscle Behavior

Results from experimental studies provide evidence for overhead work as a cause of proximal upper extremity muscle fatigue, a suggested predictor of subsequent PUE symptoms and disorders. Signs of muscle fatigue in the trapezius and supraspinatus increased when arm abduction angle increased from 45° to 90° (Herberts et al 1980). Signs of supraspinatus fatigue occurred within 15 seconds after arm flexion and abduction to 90°; additionally, signs of trapezius fatigue were present within 60 seconds of abduction at 90° (Hagberg 1981a). Time to fatigue was shorter when performing contractions at 90° compared to 0° flexion (Kahn and Monod 1984). Signs of fatigue in the infraspinatus and trapezius increased when arm flexion and abduction changed from 45° to 90°, though the same increase in signs of fatigue was not seen in the supraspinatus (Sigholm et al 1984). Jarvholm et al (1988b) demonstrated that supraspinatus blood flow was impeded at 90° upper arm flexion and even more so in abduction, with or without a hand load. Supraspinatus activity increased when performing dynamic work at 90° elevation compared to static hold at 90° (Sporrong et al 1998). Postural tremor in the PUE and total body residual discomfort increased during overhead work (Wiker et al 1989). Work by Garg et al (1999) showed that maximum acceptable frequency was lower, arm down time was greater, and ratings of perceived exertion, fatigue, and pain were greater with flexion angle at 90° and 120° compared to 60°; additionally, the weakest arm postures were 90° and 120° flexion, compared to 0°, 30°, 60°, and 150° upper arm flexion.

Results from experimental studies have suggested that work with the upper arm elevated lower than overhead also generates proximal upper extremity fatigue. Signs of increased localized muscle fatigue in the supraspinatus were found for 45° abduction compared to 0° abduction (Herberts et al 1980). Increased activity in the infraspinatus, trapezius, and supraspinatus was found in 45° elevation compared to 0° elevation (Sigholm et al 1984). Jarvholm et al (1988b) demonstrated that blood flow in the supraspinatus was impeded even at low to moderate levels of abduction with or without a hand load; additionally, during low to moderate levels of flexion, supraspinatus blood flow was impeded with a hand load of two kilograms.

CHAPTER III

EPIDEMIOLOGY OF THE PROXIMAL UPPER EXTREMITY

Difficulties with Nosology, Choice of Health Outcome, and Exposure Assessment

Aside from physician-diagnosed disorders, the epidemiological literature contains numerous terms to describe proximal upper extremity problems, such as occupational cervicobrachial disorder, shoulder impingement syndrome, shoulder girdle pain, and a variety of shoulder symptoms, including pain, complaints, stiffness, fatigue, or tenderness. These examples are only a sampling of the terms used to depict disorders and symptoms in that region. Some terms found in the literature imply that an etiology of the disorder is known without having established that connection. For example, use of the terms '*occupational* cervicobrachial disorder' or '*work-related* cumulative trauma disorder' both imply that the disorder is inherently related to work. In addition, use of the word 'cumulative' implies that the disorder gradually accumulates over time, when gradual onset may not be the pathogenesis.

Other authors have lamented the plethora of nomenclature describing PUE disorders. Anderson (1984), in a discussion of rheumatology of the shoulder, purported that painful arc syndrome may occur simultaneously with tension neck, the combination of which has been described numerous, synonymous ways in the literature, including cervicobrachial syndrome, neck and upper limb disorders, neck-shoulder problems, repetitive strain syndrome, or shoulder girdle pain. Wallace and Buckle (1987) reviewed the ergonomic aspects of neck and upper limb disorders. They, too, acknowledged the overabundance of designations in the literature that classify neck and upper limb complaints, the fallacies of most epidemiological studies in defining neck and upper limb symptoms or disorders, and the dearth of problems related to occupational exposure measurements. Hadler (1989) was bolder in his account of the number of superfluous terms describing PUE illness: he claimed they were "…littering the contemporary lexicon."

Some authors provided valuable insight on the approach to evaluating the impact of epidemiological studies. Hadler (1977) argued that the literature supporting the assumption that regional musculoskeletal disease is use-associated is almost entirely anecdotal. He noted that usage must be involved with degenerative joint disease since morbidity is, in part, defined by the impairment. Hadler emphasized the importance of identifying a usage pattern that contributes to specific clinical syndromes, and encouraged investigators to remember that diseases of individuals are under study, not diseases of industries. Hadler ended with a reminder that results from a particular study cannot be relevant to any group but the one under study. He suggested that valuable, reliable pieces of information can be gleaned from properly designed studies, and only then can the hypotheses be scrutinized. Sommerich et al (1993) presented a comprehensive review of the literature regarding soft tissue disorders of the shoulder. The authors also lamented the lack of well-defined diagnoses, the accepted grouping of shoulder or shoulder-neck disorders with different or unclear etiologies, and the deficiency of longitudinal cohort studies in the epidemiological literature. They implored future researchers to provide clear case definitions and either objective or comparable exposure definitions.

Health outcomes in the epidemiological literature are often established using subjective outcomes obtained from health questionnaire data, instead of being physician-diagnosed disorders. Health outcomes in many epidemiological studies lack clinical or anatomic specificity. The PUE is frequently analyzed together with the neck, and sometimes the distal upper extremity (DUE), making it difficult to elicit information specific to the PUE. The health outcome is sometimes considered in conjunction with an onset stipulation, latent period, or other constraint, making comparisons among studies complicated. Non-specific exposure assessment methods have historically been employed. For example, job title, rather than objective measures of exposure, has often been used as a measure of exposure. Additionally, exposure measures for the DUE have been used to describe exposure in the PUE. Regardless of the inconsistencies in the epidemiological literature regarding the PUE, it is certainly not without merit. As long as study limitations are acknowledged, results from these studies can illuminate potential risk factors for the development of PUE disorders.

Personal Risk Factors

The Impact of Age

While results from pathology studies were primarily concordant with regard to the relationship between advanced age, degeneration, and subsequent development of proximal upper extremity disorders, epidemiological studies that evaluated age as a risk factor for proximal upper extremity subjective and objective health outcomes produced conflicting evidence. Some studies reported more subjective shoulder symptoms, pain, or fatigue with advanced age (Dimberg et al 1985, Kamwendo et al 1991, Ignatius et al 1993, Niedhammer et al 1998). Other studies found no relationship with age and the presence or development of subjective shoulder symptoms (Knave et al 1985, Chang et al 1987, Jeyaratnam et al 1989, Flodmark and Aase 1992, Westgaard and Jansen 1992, Hoekstra et al 1994, Schibye et al 1995).

Studies with objective measures as health outcomes were similarly divided. Higher age was associated with outcomes including degenerative tendinitis, physician-diagnosed “shoulder disorders” and “shoulder complaints,” and soft-tissue shoulder conditions (Bjelle et al 1979, Kvarnstrom 1983, English et al 1995, Van der Windt et al 1995). Other studies reported no relationship between advanced age and diagnosed shoulder disorders (Luopajarvi et al 1979, Bjelle et al 1981, McCormack et al 1990, Hales et al 1994, Frost and Anderson 1999). In those studies where evidence of association between age and shoulder symptoms or disorders was found, the impact was maximal between approximately 40 to 65 years of age.

The Impact of Gender

In the same way that PUE pathology studies were not in agreement regarding the effect of gender, it was unclear the impact gender had on proximal upper extremity symptoms and disorders in epidemiological studies. Female gender was a potential risk factor for subjective PUE health outcomes in some epidemiological studies (Dimberg et al 1985, Knave et al 1985, Skov et al 1996). Other studies found no relationship between gender and subjective health outcome (Chang et al 1987, Bergenudd et al 1988, Hoekstra et al 1994, Nordander et al 1999). When the health outcome was objectively-determined, gender was more often not an influence (McCormack et al 1990, Hales et al 1994, Frost and Anderson 1999). However, some studies did find female gender as a risk factor for objectively-determined PUE disorders (Kvarnstrom 1983, Nordander et al 1999). The relationship between gender and proximal upper extremity symptoms and disorders remains unclear.

The Impact of Duration of Employment

The epidemiological literature contained a few studies that found an association between longer duration of employment and proximal upper extremity *disorders* (Kilbom et al 1986, Stenlund et al 1992, Andersen and Gaardboe 1993b). However, studies less often showed a relationship between PUE *symptoms* and longer duration of employment (Kamwendo et al 1991, Andersen and Gaardboe 1993a). Years of experience provided a protective effect from disorders in some studies (Kadefors et al 1976, Herberts and Kadefors 1976, Frost and Anderson 1999). Many studies found no relationship between duration of employment and shoulder symptoms or disorders (Chang et al 1987, Jeyaratnam et al 1989, McCormack et al 1990, Milerad and Ekenvall 1990, Chiang et al 1993, Stenlund et al 1993, Hales et al 1994, Hoekstra et al 1994, Schibye et al 1995, Lundberg et al 1999). The role of duration of employment as it affects PUE disorders or symptoms is unclear. The relationship, if any, is likely job and task-dependent and would not be expected to be fully explained only by duration of employment.

The Impact of Strength

Few studies have evaluated the role of shoulder strength as a predictor for shoulder symptoms or disorders, and the results are conflicting. Some epidemiological evidence exists for lesser proximal upper extremity muscle strength as a predictor of shoulder symptoms or disorders (Bjelle et al 1987, Kilbom 1988). Other studies have demonstrated no evidence that a relationship between strength and PUE symptoms or disorders exists (Kilbom 1988, Takala and Viikari-Juntura 1991).

Job Risk Factors

The Impact of Postural Activity and Load

Epidemiological evidence for overhead work as a risk factor for PUE symptoms and disorders has been found, especially with increasing duration of time spent working overhead. Symptoms and disorders associated with overhead work in epidemiological studies include supraspinatus fatigue, shoulder stiffness, tenderness, or pain, supraspinatus tendinitis, degenerative rotator cuff tendinitis, and more communal classifications such as musculoskeletal disorders of the shoulder or simply, shoulder disorders (Herberts and Kadefors 1976, Kadefors et al 1976, Bjelle et al 1979, Sakakibara et al 1987, Sakakibara et al 1995, Welch et al 1995, Hughes et al 1997, Punnett et al 2000).

Additional epidemiological evidence has been presented supporting upper arm elevation (flexion or abduction) as a risk factor for proximal upper extremity symptoms and disorders. The evidence increases with duration and frequency of time spent working with elevated arms. Specific elevation sectors associated with increased risk were elevation greater than 30°, 45°, and 60° compared to smaller angles or sectors, depending on the study. Some evidence contrary to upper arm elevation as a risk factor was presented (Fine et al 1986, Bjelle et al 1987); however, the majority of studies suggested a positive relationship (Bjelle et al 1981, Dimberg et al 1985, Kilbom et al 1986, Milerad and Ekenvall 1990, English et al 1995, Hughes et al 1997, Frost and Anderson 1999, Punnett et al 2000).

Some epidemiological evidence has been found supporting increased repetitive upper arm activity or increased speed of work as risk factors for PUE symptoms and disorders (Luopajarvi et al 1979, Wiker et al 1989, Lo et al 1990, Ekberg et al 1994, Punnett et al 2000). One study reported a negative association between shoulder symptoms and repetitive arm elevations, though in this study, degree of elevation was not distinguished (Kilbom et al 1986). Additionally, some evidence has been found supporting greater load on the PUE as a risk factor for PUE symptoms or disorders (Stenlund et al 1992, Niedhammer et al 1998). Other studies have found no evidence supporting increased load on the PUE as a risk factor for symptoms or disorders (Stenlund et al 1993, Punnett et al 2000). Measures of muscle load after repetitive upper arm elevations indicated fatigue in muscles of the PUE, particularly with increased hand load (Hagberg 1981b) and with the presence of pre-existing pain (Larsson et al 1999).

Measures or definitions of repetition and load are often dependent on each other, and vary widely across studies. Even so, some conclusions can be drawn. The epidemiological evidence suggests that repetition is a possible risk factor for PUE disorders, especially when a painful condition is already present; however, the evidence is less clear regarding PUE symptoms. The epidemiological evidence supporting load as a risk factor for neck/shoulder or PUE-specific symptoms and disorders is less apparent.

The Impact of Vibration

Some epidemiological evidence has been found supporting the presence or estimated hours of vibration as a risk factor for proximal upper extremity symptoms or disorders (Dimberg et al 1985, Stenlund et al 1992, Stenlund et al 1993). Other studies have not found support for such a relationship (Burdorf and Monster 1991). The number of studies evaluating vibration as a risk factor is small and conclusions are difficult to draw.

Epidemiological Study Reviews

Other major reviews of the epidemiological literature regarding shoulder disorders have been conducted. Conclusions from these reviews were generally concordant with the current review of epidemiological and PUE disorder pathology literature. Over the course of comparing data from different occupations, Hagberg and

Wegman (1987) concluded that highly repetitive shoulder muscle contractions, static contractions, and work at shoulder level were hazardous exposure factors. In a large-scale initiative to identify workplace factors that contribute to musculoskeletal disorders, contributors evaluated four classically-touted ergonomic risk factors (Bernard et al 1997). They found evidence of a positive relationship between repeated or sustained shoulder flexion/abduction postures greater than 60° and shoulder musculoskeletal disorders. Limited evidence of positive association was found for highly repetitive work and shoulder musculoskeletal disorders. Insufficient evidence of association was found between force and shoulder musculoskeletal disorders. Insufficient evidence was found between vibration and shoulder musculoskeletal disorders. Conclusions were based on a limited number of studies that met a set of evaluation criteria.

CHAPTER IV

ASSESSMENT TECHNIQUES FOR THE PROXIMAL UPPER EXTREMITY

Though several authors have implored for the consistent measurement of study variables and the development of better ergonomics assessment tools, there are currently none with demonstrated ability to identify jobs which are associated with increased risk of proximal upper extremity disorders. Many approaches to risk assessment have been suggested, which range from guidelines and checklists, task analysis techniques, and posture analysis techniques, to indirect approaches such as fatigue analysis, use of psychophysical tables, and body part discomfort surveys. On some level, the subsequently discussed approaches have merit in the principles behind them. Some map more closely to the theories of pathogenesis of PUE disorders than others. Many of the job analysis techniques available are not necessarily specific to the proximal upper extremity.

Some researchers have provided suggestions on how to begin assessment tool development or have defined task variables and risk factors of interest. Rohmert (1962) clarified the use of the terms ‘stress’ and ‘strain.’ Stress was defined as the sum of all work parameters that influence a person, and included any demands placed on the body. Strain was defined as a function dependent equally on stress factors and individual capacities. The measures of stress and strain were defined as time-dependent and work-level dependent; therefore, it was proposed that intensity and duration of work must be considered when evaluating a job. Westgaard (1999) discussed Rohmert’s force-fatigue curve (Rohmert 1960) and asserted that workers can develop musculoskeletal disorders at considerably lower levels than those suggested by the curve as safe. In agreement with Rohmert (1962), Westgaard noted that physical workload is dependant on level, force variation pattern, and duration.

Hagberg (1992) maintained that the field of ergonomics is new to epidemiology, thus most ergonomists have little practice in epidemiological study design. Hagberg purported that one of the problems with ergonomics compared to, for example, industrial hygiene, is the difficulty of exposure definition, measurement, and evaluation, which was also noted by Bjelle (1989) and Stock (1991). A unifying definition of exposure would make studies more comparable. He recommended using posture as defined by the American Academy of Orthopaedic Surgeons (1965), which presented definitions of neutral and non-neutral positions of joints. Hagberg opposed the use of job title alone as an exposure variable. He noted that a few studies went further and developed exposure variables that described the jobs in terms of posture, motion, or work organization, yet usually only one of the descriptors ended up being emphasized as a benchmark of exposure. Hagberg additionally noted that exposure is often assessed by questionnaire, which further confounds analysis. He clarified dose definition as the amount of physical stress in the musculoskeletal system and suggested that use of biomechanical computation, electromyography, or perceived exertion would provide a measure of dose. Hagberg reemphasized that exposure and dose categorization should have some basis in work physiology. He stressed avoiding the arbitrary choice of threshold levels. Use of an exposure profile, rather than a single estimate of exposure for risk assessment, was recommended. He advocated presentation of exposure and exposure categories such that preventative measures could be suggested. Lastly, Hagberg reminded readers that the presence of any force or repetition is not necessarily dangerous, as they can be used to build muscular strength and endurance and are a necessary part of daily activities.

Armstrong et al (1993) proposed an abstract model for work-related neck and upper limb musculoskeletal disorders. The authors noted the importance of distinguishing between “occupational disease” and “work-related disease.” They suggested that use of the word “occupational” should only imply a direct cause and effect mechanism, while the term “work-related” should imply that work is a contributing factor to a multifactorial cause. Unfortunately, that distinction had been largely ignored among the plethora of epidemiological studies to date and subsequent to publication. They, too, remarked upon the wide variation in case definitions and methodology in the epidemiological literature. The authors provided a dose-response model structure. The proposed model contained four “state variables:” (1) exposure: external factors that produce internal dose, such as work requirements, (2) dose: factors that alter the internal state of the individual (can be mechanical, physiological, or psychological), (3) capacity: ability to resist destabilization from dose, and (4) response: changes that occur in an individual, such as shape of tissue.

Use of self-reported exposure data has problems with relevance and repeatability as demonstrated by Wiktorin et al (1993). The authors showed that self-reported exposure in a questionnaire regarding elements of manual materials handling was too crude when tested beyond a dichotomous level. Even at a dichotomous level, agreement was dependent on the question and was not always good. Use of questionnaire results as the basis for establishing exposure and health outcome is a common risk assessment technique in epidemiological studies. As such, results from epidemiological studies should be evaluated critically.

Guidelines and Checklists

Noting the presence of one or more generic risk factors has historically been used as a quick job assessment or in some cases, justification for declaring a job to be ‘unsafe.’ The risk factors most frequently cited in relation to the proximal upper extremity include repetitiveness, forcefulness, awkward posture, and vibration. The predictive validity of using stand-alone generic risk factors without clarifying parameters to assess risk of PUE disorders has not been established. Armstrong et al. (1986) discussed job evaluation with respect to generic work risk factors. The authors noted that the presence of a generic risk factor does not imply that an injury will occur; however, it was postulated that in conjunction with a history of injuries, the nature of the job may play a role in the injury process. Additionally, generic risk factor *presence* is not in concordance with proposed theories of pathogenesis of PUE disorders.

Winkel and Westgaard (1992) generated guidelines for the occupational safety practitioner regarding enhanced worker safety and productivity. The authors suggested that an approach to job analysis should contain a description of physical exposure, including estimates of exposure levels, repetitiveness, and durations. The authors noted the importance of recording the pattern of activity and rest. They defined a course of action based on the exposure level of the work task: (1) “low” exposure level: good workstation design according to ergonomics texts, (2) “medium” exposure level: work with elevated shoulders or arms, or a deviated neck; tool contribution to the biomechanical load negligible compared to body weight contribution, and (3) “high” exposure level: large force exertion in the shoulder-neck region, such as when using heavy tools with arms deviated from the vertical position. The authors recommended durations for each task exposure level, discussed modifying duration factors (such as monotonous work tasks, poor psychosocial environments, or lack of breaks or alternative tasks), and discussed jobs with multiple levels of exposure.

The State of Washington proposed an Ergonomics Rule (Washington State Department of Labor and Industries, 2000) which was established to assist businesses in identifying “caution zone” jobs based on the presence of certain work conditions. If those work conditions are present, a work-related musculoskeletal disorder (WMSD) hazard is considered present. The conditions must then be eliminated or reduced to the degree technologically or economically feasible. The rule contains postural conditions for the shoulder, neck, back, and knee, conditions based on hand force estimates, repetition conditions, repeated hand impact conditions, lifting conditions, and vibration conditions. For the shoulder, working with the hand(s) above the head or working with the elbow(s) above shoulder level for greater than four hours duration are considered risk factors. Additionally, raising the hand(s) above the head or raising the elbow(s) above the shoulder more than once per minute for greater than four hours duration are also considered risk factors. No evidence of predictive validity has been established using the Washington State Ergonomics Rule.

Task Analysis Techniques

Anderson (1971) lamented the fact that rheumatic disease lacks standardization in the epidemiological literature, and proposed a job analysis technique based on job task descriptions rather than simply job titles. The classification system was called BAHLPS (Back, Arms, Hands, Legs, Posture, and Site). A job is classified into one of five grades for three aspects of a job: (1) individual grades for the back, arms, hands, and legs (Grade I: no effort – Grade V: maximum effort sustained for long periods), (2) posture (Grade I: mainly sitting or standing in one position – Grade V: walking long distances), and (3) site (Grade I: office or heated workshop with only occasional outdoor work – Grade V: outdoors all weathers). A validation effort indicated that among 164 workers with grade I or II ("light") on all four body part assessments, 44% had rheumatic complaints, while among 462 workers graded IV or V ("heavy"), 43% had rheumatic complaints. Validation results were inconclusive, though the author reported no effect of site conditions. The BAHLPS technique lacks PUE specificity.

Wangenheim et al (1986) introduced a "person-adjusted" ergonomic method for systematic force analysis. The method involves evaluating representative work cycles via videotape and coding the postural, force, vibrational, and static loads at freeze-framed portions of the videotape with the help of guidelines. The method divides the body into fourteen "functional units." For each unit, the observer can choose, from a series of pictures, a pose that most closely represents the actual posture of the given unit. Poses are separated into "normal," "comfort zone," or "extreme," based on an experiment where subjects rated discomfort on a Borg scale. Force load is described in values from 0 to 10. Force for each pose was estimated using anthropometric data and biomechanical analysis. If measured force is not possible, force ratings can be used as a substitute. Vibration is measured both with subjective assessments of vibration and knowledge of actual tools handled. Static load is recorded based on results from experiments of endurance time at different load levels. Work analysis is organized via a computer program. Based on evaluation of the methodology in small-scale industrial experiments, the authors purported its usefulness in reducing ergonomic load, though no validation was reported. Though the method provides a framework for force measurement when objective measures are unavailable, the method lacks specificity and does not provide any measure of risk of PUE injury.

Drury (1987) developed a method to evaluate the "repetitive motion injury potential" of a job. He rightly acknowledged that any system should be model based, rather than descriptive. When evaluating repetition, force, frequency, or posture, Drury proposed that 'less' is always better. After obtaining body angles based on observation, angles are categorized into zones of exposure, which are mathematically divided sectors based on range-of-motion data. For the shoulder, measured body angles include outward rotation, inward rotation, abduction, adduction, flexion, and extension. Zone 0 ("no exposure") is neutral ± 10% of range, Zone 1 ("low exposure") is ± 10% to ± 25% of range, Zone 2 ("moderate exposure") is ± 25% to ± 50% of range, and Zone 3 ("severe exposure") is greater than ± 50% of range. The frequency of "daily damaging motions" can be tabulated, based on the frequency of occurrence in each zone. Drury also recommended using body part discomfort surveys in conjunction with task analysis. Analyses should be performed before and after interventions. Predictive validity of this technique was not reported.

Kilbom (1994) suggested guidelines for repetitive work of the upper extremity. Repetitive was defined as "…the performance of similar work cycles, again and again." It was clarified that the output of repetitive work is similar from one cycle to the next and that cycles should resemble each other with regard to time and force exertion pattern. For the purposes of the guideline, Kilbom characterized 'repetitive' work as either: (1) a work cycle less than thirty seconds, or (2) when one fundamental work cycle constituted greater than 50% of the total cycle, independent of cycle time, which aligned with work by Silverstein et al (1986). To adjust for physiological and biomechanical demands, Kilbom suggested repetitive work be further classified as either: (1) intermittent static (external movement minor), or (2) dynamic (external movement easily distinguishable). Kilbom's guideline also required work duration to be at least sixty minutes in order to be considered repetitive. Once a task has been declared repetitive, four additional descriptors should be employed: (1) time (frequency of specific movements, duration of work cycle and cycle elements, duration of intermittent static contractions, exposure time over the course of a day), (2) subjective force (high or low), (3) dichotomized posture (neutral/small or moderate/extreme), and (4) dichotomized speed (static/slow or fast). Kilbom suggested gathering data on disorder rates via questionnaire, worker’s compensation claims, OSHA injury/illness records, or clinical exams, and emphasized that disorders should be clarified as either tendon or muscle disorders and defined by upper extremity segment. Kilbom proposed that tasks with dynamic shoulder movements greater than 2.5 per minute and dynamic upper arm/elbow movements greater than 10 per minute were high risk tasks. Modifying factors that would elevate the risk level to “very high” were presented: high external force, high speed, high static load, extreme posture, lack of training, high demands on output, monotony, lack of control, and long duration of repetitive work. Though Kilbom suggested a validation methodology, no validating data was presented. This technique lacks PUE specificity.

Buchholz et al (1996) presented a job analysis technique called PATH (Posture, Activity, Tools, and Handling) which is based on work-sampling, for industries with irregular or non-repetitive work. Originally developed for use in the construction industry, PATH is a task-based analysis methodology that involves: (1) identifying a job site, (2) performing a site review to describe operations and tasks, (3) interviewing workers, (4) collecting data such as tool weights and materials handled, (5) task sampling, and (6) documentation via videotape and photographs. One of the coded data elements is posture, with sectors modified from Karhu’s work (1977 and 1981). PATH maintained Karhu’s three original upper limb categories: (1) ‘neutral’ (both elbows below shoulder height), (2) ‘one arm raised’ (one elbow above shoulder height), and (3) ‘two arms raised’ (both elbows above shoulder height). In addition to coding posture, PATH requires coding of fundamental task activities, tool use, grasp type, and load handled (ascertained either via direct measurement of tool/object weight or indirectly via standard construction material data). Frequencies of postures, activities, and loads are also recorded. The authors noted that partial validity of the PATH method was assessed by comparing PATH trunk posture codes to results from a real-time, computer-aided job posture analysis method developed by Keyserling (1986). They found the PATH method to “…be reasonably valid and reliable.” The PATH method lacks PUE specificity.

Colombini (1998) introduced an observational method for classifying repetitive movements of the upper limbs. The author recommended describing the work by breaking it into tasks, cycles, and technical actions, while noting any recovery time that occurred. Repetitiveness was defined as “the presence of events (cycles/technical actions) that are repeated in time, always the same.” It was emphasized that frequency, rather than repetitiveness defined via cycle time, may be a better predictor of disorders because it is possible that shorter cycles may not have frequent activities, while longer cycles may have a higher frequency of activities. A posture scoring system was recommended for each upper limb joint (shoulder, elbow, and wrist) that accounted for duration of cycle time spent within specific angular sectors, variation of posture, and time spent within extreme ranges of motion. Score modifying factors were also suggested, such as use of vibrating tools or exposure to cold. Additionally, based on the presence or absence of recovery periods in a repetitive work day, each hour of the day was classified as “risk-free” or “at-risk” (work:rest ratio between 5:1 – 6:1, “risk-free”; ratio between 7:1 – 10:1, risk level=0.5; ratio greater than 10:1, “at-risk”). Predictive validity of the technique was not reported.

Hignett and McAtamney (2000) developed Rapid Entire Body Assessment (REBA) to assist practitioners in evaluating postures in workplaces with irregular or unpredictable activities. Regions of the body were divided into angular sectors and a scoring system was developed. Within the scoring system, individual scores based on postural location can be obtained for the trunk, neck, legs, upper arm, lower arm, and wrist, with modifying factors incorporated if necessary. Scores from the trunk, neck, and legs are combined (“Score A”), modified by the presence of force. Scores from the upper arm, lower arm, and wrist are combined (“Score B”), modified by the degree of coupling. “Score C” incorporates “Score A” and “Score B,” which is additionally modified by an “activity score,” and includes other modifiers such as repetition and static work. Based on this final score, five action categories were suggested, from “negligible” to “very high.” Upper arm sector point values included: (1) -20° to 20° extension/flexion, (2) less than -20° extension and 20° and 45° flexion, (3) flexion between 45° and 90°, and (4) greater than 90° flexion. The upper arm score was modified if abduction or rotation was present or if the shoulder was raised (shoulder shrug). Since REBA combines exposure scoring for the proximal and distal upper extremity, the tool lacks PUE specificity. Predictive validity of this technique has not been established.

Bloswick and Villnave (2000) presented a method of estimating shoulder moment using tables based on gender and arm posture. The authors proposed using the ratio of the shoulder moment required by the task (calculated using a provided worksheet) and the gender-specific maximum strength in that posture. They acknowledged that no generally accepted limits for shoulder moment exist, but proposed that a ratio less than 0.5 would not be a hazard for most workers unless high frequency was present and that a ratio greater than 1.0 would present a hazard for most workers. Predictive validity of this method has not been reported.

Postural Analysis Techniques

Priel (1974) proposed a numerical definition of posture under the assumption that the body can be divided into fourteen parts (two hands, two forearms, two arms, two thighs, two legs, two feet, one trunk, and one head). The author proposed use of the "Posturegram," a form for recording posture data based on observation in three planes: transverse, frontal, and sagittal. Limb movements were split into numbered angular sectors, with positive or negative deviations noted. The Posturegram was meant to be used as a tool to describe postural characteristics of a job rather than provide any evidence of disorder risk.

Work by Karhu et al (1977, 1981) has long been employed as a source for evaluating postural demands in the workplace. The authors developed the Ovako Working Posture Analysing System (OWAS), which is based on work sampling. It is a method of whole-body classification of the back, upper limb, and lower limb postures. Each body segment is assigned a number code, based on a chart of figures maintaining different positions; thus, each whole-body posture can be represented by a three-digit code and jobs can be subsequently prioritized for change. The back has four code choices, the upper limb has three, and the lower limb has seven. For the upper limb, Code 1 is used when both arms are at or below shoulder level, Code 2 is when one limb is at or above shoulder level, and Code 3 is when both limbs are above shoulder level. After the three-digit code is established, postures are further classified into one of four whole-body priority classifications, called “operative classes.” No mention of an algorithm to determine which three-digit posture codes fall into which operative classes was presented, though generally speaking, smaller body region codes were considered to be more optimal.

Kant et al (1990) evaluated a group of mechanics using the OWAS system. The authors indicated that placement in a certain action category is based on both the OWAS code and the percentage of the working day spent working within that code. The authors were able to identify job tasks which fell into the highest operative class and propose load-reducing postures to replace the original postures. Chaffin et al (1999) presented the schematic for OWAS action categories, based on both the position of the specific body region and the percentage of time spent within that position. Four action categories were discussed, including: acceptable, slightly harmful, distinctly harmful, and extremely harmful. For the shoulder region, spending greater than 80% of time with both elbows above shoulder level or greater than 90% of time with one elbow above shoulder level was considered “distinctly harmful.” Spending between 30% - 79% of time with both elbows above shoulder level or 40% - 89% of time with one elbow above shoulder level was classified as “slightly harmful.” The remaining possible percentages were considered “acceptable.” Predictive validity for the OWAS technique has not been established.

Corlett et al (1979) developed a method for recording whole-body postures, which required making ten marks on a chart, representing deviations from standard positions in various body regions. The technique was developed primarily to identify the presence of awkward postures, though it does not account for duration of time holding a particular posture or recovery time. Validation of this tool has not been established.

In a report on an investigation of cumulative trauma disorders in a poultry processing plant, Armstrong et al (1982) presented a system for describing joint position. Though the bulk of the system was intended for analysis of the distal upper extremity, the authors added shoulder posture descriptors, which were defined about three axes. Extension and flexion were divided into 45° sectors, with "neutral" defined as 0° - 45° flexion, and with all extension angles grouped together. Adduction and abduction, referenced from the transverse plane, were also divided into 45° sectors, with all adduction angles grouped together and "neutral" defined as 0° - 45° abduction. Lateral and medial rotation were divided into 45° sectors, with all lateral rotation grouped together and 0° - 45° medial rotation defined as "neutral." No explanation for the choice of shoulder sector divisions was given. However, Armstrong (1986) asserted that the reasoning behind the division of joint range of motion into sectors was because it is not usually possible to reproduce angle measurements to the exact degree, especially when secondary analyses are performed, such as videotape analysis. The authors were correct that angular degree of posture cannot be measured explicitly from secondary sources; however, sector divisions should not be arbitrary.

Keyserling (1986a & 1986b) discussed a methodology to analyze postures of the trunk and upper limb. Keyserling described a computer-aided postural analysis system that allowed for changes in posture sectors (time within and frequency between) to be tracked by hitting a key. The system generates a posture profile for a job, identifying the frequencies of sectors in each body region, the minimum, maximum, mean, standard deviation, and total time spent within each sector, and the percentage of the job cycle in each sector. The system also generates a graph which demonstrates task analysis and postural activity of the body regions on a common time scale. Upper limb posture sectors included "neutral" (flexion/abduction less than or equal to 45°), "mild" (flexion/abduction greater than 45°, but less than or equal to 90°), and "severe" (flexion/abduction greater than 90°). Keyserling emphasized a sequence for postural job analysis, which included: (1) videotape job at worksite and sketch workstation, (2) develop sequential task description, (3) computer-aided posture analysis, (4) posture profile posture graph, (5) identify causes of postural stress, and (6) redesign job. Validation of this technique has not been established.

Genaidy et al (1993) developed a schematic for a postural stress analysis system to evaluate stresses in an industrial environment. The described methodology was confusing, but the authors concluded that the multipliers developed to weigh the impact of various body movements were valid. The system relies on visual perception to classify working posture from videotapes. Validation of this method has not been established.

Wiktorin et al (1995) presented an observational method for recording postures at work called HARBO, which stands for "hands relative to the body." The method was developed on the assumption that the position of the hands is related to the postural demands on the shoulder, neck, and low back. The body is divided into three sectors: hands above shoulder level, hands between shoulder and knuckle level, and hands below knuckle level. The duration of five work postures are recorded: (1) standing or walking with hand(s) above shoulder level, (2) standing or walking with hands between shoulder and knuckle level, used to describe "fixed" postures (carrying greater than 50 N also falls in this category), (3) standing or walking with hands not fixed between shoulder and knuckle level, as when work is performed that does not require the use of two hands, such as making a telephone call (carrying less than 50 N falls in this category), (4) standing or walking with hands below knuckle level (also includes stooping, kneeling, and squatting), and (5) sitting. A computer program was developed to track posture changes and durations, requiring only occasional keying by the observer. Though small scale inter-rater and inter-method studies were executed with fairly reliable outcomes, no attempt was made to correlate posture data with injury-illness data.

Other Assessment Methods

Snook and Ciriello (1991) published a series of tables containing maximum acceptable weights and forces across genders and percentiles of the population. The tables were based on a compilation of results from several psychophysical studies. Tasks included lifting in the upper arm range. Data was provided for dynamic lifting, lowering, pushing, pulling, and carrying categorized by variables such as vertical travel distance and frequency of task. Though the tables were not developed to specifically assess risk of upper extremity disorders, the information provides insight into the interaction between task, load, and posture. The maximum acceptable limits may have been limited by the shoulder.

The two-dimensional static strength prediction model (2DSSP), as developed by Chaffin and associates at The University of Michigan, and described in the 1999 Occupational Biomechanics text, predicts the proportion of a population that would be capable of performing a specific lift, push, or pull. The percentage capable is separated by joint, including the elbow, shoulder, L5/S1, hip, knee, and ankle. Such a tool can be useful in evaluating a job with repeated or consistent tasks.

Rodgers (1987) described a technique for scheduling repetitive tasks and recovery time. The technique is based on the physiologic mechanisms behind repetitive motion injuries. Rodgers referred to work by Rohmert (1973) and Lind and McNichol (1967), who demonstrated that muscle circulation is related to the varying levels of muscle effort; that is, the higher percent maximum voluntary contraction (%MVC), the more circulation is compromised and the time to fatigue decreases. Additionally, Rodgers pointed out that the recovery time needed for muscle effort greater than 70% MVC is larger than the time to hold that effort. The author theorized that circulation to the tendons and tendon sheaths may be similarly compromised by increased muscle effort. Rodgers presented data modified from Rohmert (1973), and constructed a graph of work time versus required recovery time, in a format easily applied to work analyses. If cycle time is known, and work time can be measured, then an acceptable effort level can be determined. Conversely, if the effort level is known, and work time can be measured, the graph indicates the shortest cycle time that can be performed without fatigue. Additionally, if the cycle time is known and effort level has been estimated, the maximum allowable work time can be predicted from the graph. Rodgers cautioned that the work/recovery graph should only be used to characterize work demands and to provide insight into jobs with possible increased risk of muscle fatigue.

Rodgers (1988) discussed techniques to evaluate job demands and determine worker capacity from the perspective of the occupational physician. The author referred to work by Rohmert (1973) and the Eastman Kodak Company (1986), who determined the intensity/duration relationships for static muscle effort and aerobic work. To characterize work capacity, the author suggested the following process: (1) define active muscle groups, (2) rate the effort intensity, (3) measure the time of continuous effort, (4) measure the recovery time between efforts, and (5) determine the percent duration of muscle effort over the workday. Effort intensity should be expressed as a percentage of the maximum strength for a particular posture.

Rodgers presented a method for screening jobs where musculoskeletal problems have historically occurred so that job changes or accommodations can be made. Three factors must be quantified: (1) effort intensity (heavy, moderate, light), (2) time of continuous muscle effort (< 6, 6 – 20, > 20 seconds), and (3) repetition frequency (< 1, 1 – 5, > 5 cycles per minute). The categories were based on physiological data suggested by Rohmert (1973) to avoid muscle fatigue. The three factors are rated for each muscle group, giving three-digit priority ratings so that the most limiting aspects of the job can be identified. Rodgers provided a priority-for-change schematic based on expected level of fatigue after five minutes of continuous work, with moderate, high, and very high classifications, and noted that any combination not appearing in the schematic should be considered low priority. In Rodgers’ method, the upper extremity muscle groups included neck/shoulders, arms/elbows, and wrists/hands/fingers.

Rodgers (1992) further clarified the effort intensity factor. For the shoulders, “heavy” effort intensity included exerting forces or holding weight with arms away from body or overhead, “moderate” effort intensity included arms away from the body without support or working overhead, while “light” effort intensity included arms slightly away from the sides or extended with some support. Rodgers additionally noted that continuous effort time and frequency of efforts should be recorded separately for each level of effort intensity, and that even very brief recovery times should be recorded.

CHAPTER V

RETROSPECTIVE EPIDEMIOLOGICAL STUDY IN A POULTRY PROCESSING PLANT

The purpose of this study was to identify task variables that may influence the occurrence of proximal upper extremity disorders by analyzing jobs at a poultry processing plant. Comparisons of PUE morbidity to measured task variables were made to determine the relationship between exposure and occurrence. A secondary purpose was to compare the hazard classification based on two models of PUE disorder pathogenesis to the observed morbidity of the poultry processing jobs. The study results will contribute to a practical hazard evaluation process for the PUE.

Methods

Exposure Assessment

Archived videotapes of workers in the poultry processing industry were available for evaluation. A total of twenty-six autonomous jobs were present in the archive. The left and right sides of the body were considered separately, providing fifty-two jobs-by-sides for analysis. A portion of each job, representative of the job's duties and containing at least one full job cycle, was digitized for more detailed analysis. For some jobs, more than one worker was videotaped performing the job. In those instances, data was collected for each individual worker and subsequent analyses were performed on the data averages. Several task variables were collected from the digitized video. The presence or absence of some task variables was observed, while other task variables were estimated from paused video screen shots captured every 0.5 seconds. Table I contains each task variable, its biological significance, assessment method, and measurement characterization.

The presence or absence of ballistic motion was observed. Ballistic motion was defined as a rapid increase in proximal upper extremity linear or angular velocity, followed by an abrupt deceleration. If ballistic motion was present, the frequency of ballistic motions per minute was calculated. It is believed that rapid activation of muscle motor units may lead to localized muscle fatigue (LMF), while repeated activation accelerates the LMF process. Additionally, high tensile loads are expected because ballistic exertions usually involve an element of eccentric muscle activation, and eccentric exertion produces the highest levels of tensile load in a muscle-tendon unit.

Presence or absence of applied hand force was observed. Applied hand force was defined as a deliberate action to initiate movement of an object using the hand, and was further characterized as either toward or away from the body. A job might contain applied hand forces both toward and away from the body. If applied hand force was present, the frequency of total applied hand forces per minute was calculated, as well as separately considering the frequency of applied hand forces toward and away from the body. It is believed that force applied by the upper extremity causes an increase in tensile load, which increases intramuscular pressure (IMP) and can lead to LMF. Applied force away from the body primarily affects the anterior deltoid, pectoralis major and minor, and the triceps, while applied force towards the body primarily affects the posterior deltoid, biceps, and scapular stabilizers.

Upper arm elevation was defined as the flexion, abduction, or extension angle between the humerus and the torso. Upper arm elevation angle, along with included elbow angle, were estimated from screen shots taken every 0.5 seconds from the digitized video by marking the shoulder, elbow, and wrist centers of rotation, connecting the centers of rotation, and manually measuring the subsequent angles. Upper arm elevation angle measurements when the torso was observed to be not upright were adjusted by drawing an additional line from the shoulder center of rotation down along the torso and measuring from that line rather than the perpendicular line that would have defined an upright torso. The presence of an object in the hand was observed, and the weight of the object, if present, was estimated based on evaluating similar poultry processing tools. It is believed that intrinsic tensile and compressive loads are affected by differing upper extremity postures and by the addition of a hand load.

Table I. Summary of the Task Variables, Their Biological Significance, Method of Assessment, and Rating Scheme

Task Variable	***Biological Significance***	***Assessment***	***Rating Scheme***
Ballistic Motion	Rapid activation of muscle motor units may lead to very high tensile loads and possibly localized muscle fatigue (LMF). Also, high tensile loads are expected because ballistic exertions usually involve an element of eccentric muscle activation, and eccentric exertion produces the highest levels of tensile load in a muscle-tendon unit	Observed	Y=Ballistic Motion Present N=Ballistic Motion Absent
Frequency of Ballistic Motion	Repeated ballistic motion accelerates tensile loading and LMF process.	Measured	Ballistic Motions/minute
Applied Hand Force	Increase in tensile load with applied force causes increase in intramuscular pressure, which leads to LMF.	Observed	Y=Applied Hand Force Present N=Applied Hand Force Absent
Applied Force Away from Body			Y=Applied Force Away from Body Present N=Applied Force Away from Body Absent
Applied Force Toward Body			Y=Applied Force Toward Body Present N=Applied Force Toward Body Absent
Frequency of Applied Force	Repeated applied force accelerates LMF process.	Measured	Applied Forces per minute
Frequency of Applied Forces Away from Body			Applied Forces Away from Body per minute
Frequency of Applied Forces Toward Body			Applied Forces Toward Body per minute
Time Measurements	Explains the temporal pattern of upper extremity exertions.	Measured	Cycle time % Duration of Time Spent with Non-Neutral Upper Arm Posture

Table I Continued

Task Variable	***Biological Significance***	***Assessment***	***Rating Scheme***
			% Duration of Time Upper Arm Angle Spent in 30 degree sectors (0-180 degrees)
			% Duration of Time Upper Arm Angle Spent in 60 degree sectors (0-180 degrees)
			% Duration of Time Included Elbow Angle Spent in 30 degree sectors (0-180 degrees)
			% Duration of Time Included Elbow Angle Spent in 45 degree sectors (0-180 degrees)
	**specific to the mechanical impingement theory of the pathogenesis of shoulder disorders		% Duration of Time Upper Arm Angle Spent at or near 80 degrees elevation (Flexion or Abduction)
			% Duration of Time Upper Arm Angle was Positive (Flexion or Abduction)
			% Duration of Time Upper Arm Angle was Negative (Extension)
Upper Extremity Posture	Intrinsic tensile and compressive loads are affected by varying upper extremity postures.		
Upper Arm Angle		Estimated	Upper Arm Angle (every 0.5 second)
		Measured	Minimum Upper Arm Elevation (Flexion, Abduction, or Extension)
			Maximum Upper Arm Elevation (Flexion, Abduction, or Extension)

Table I Continued

Task Variable	*Biological Significance*	*Assessment*	*Rating Scheme*
	**specific to the mechanical impingement theory of the pathogenesis of shoulder disorders		Mean Upper Arm Elevation (Flexion, Abduction, or Extension) Median Upper Arm Elevation (Flexion, Abduction, or Extension) Frequency of Non-Neutral Upper Arm Posture per minute Frequency Upper Arm Elevated through 80 degrees Abduction or Flexion per minute
Included Elbow Angle		Estimated	Included Elbow Angle (every 0.5 second)
		Measured	Minimum Included Elbow Angle Maximum Included Elbow Angle Mean Included Elbow Angle Median Included Elbow Angle
Presence of Upper Arm Angle Extension		Observed	Y=Upper Arm Extension Present N=Upper Arm Extension Absent
Shoulder Moment	Represents muscle strength required to maintain upper arm posture. Intrinsic loads will vary as moment changes due to upper arm posture. Extrinsic load (object) modifies shoulder moment.	Measured	Mean Shoulder Moment for a 50th Percentile Male
Moment Due to Arm Weight Only			Maximum Shoulder Moment for a 50th Percentile Male
Moment Due to Arm Weight + Object Weight			Mean Shoulder Moment for a 50th Percentile Female
			Maximum Shoulder Moment for a 50th Percentile Female

It was assumed that the upper arm elevation angles and included elbow angles measured every 0.5 seconds throughout the job cycle were representative of all the postures that would occur during the job. The angles were characterized by their minimum, maximum, mean, and median values. Presence of upper arm extension was observed.

The upper arm elevation angle and included elbow angle data was stratified into angular sectors. The percent duration of time spent within each sector was determined using job cycle time as the denominator. Two different sector schemes were explored for both upper arm elevation angle and included elbow angle. Sector divisions of 30 degree and 60 degree increments were investigated for upper arm elevation angles between 0° and 180°. Upper arm elevation angles less than 0° (extension) were grouped into one sector. Sector divisions of 30 degree and 45 degree increments were explored for included elbow angles greater than 90° up to 180°. Included elbow angles between 0° and 90° were considered one sector. Figures 1 and 2 illustrate the initially explored upper arm elevation and included elbow angle sector division schemes, respectively.

A secondary stratification of the upper arm elevation angle data was explored where all “neutral” elevation angles were grouped in one sector. Non-neutral was defined as upper arm elevation angle greater than approximately 15°, or, humeral elevation great enough to impact the moment at the shoulder. That is, at an upper arm elevation angle of approximately 15°, the associated shoulder moment rapidly begins to increase (peaking at 90° elevation). The percent duration of time spent in neutral upper arm posture was calculated using job cycle time as the denominator. The frequency of non-neutral upper arm posture per minute was recorded, represented by the number of times the humerus moved in and out of a neutral position. As an extension of choosing the definition of neutral upper arm posture to be less than or equal to 15°, another angular sector was defined to include angles greater than 15° but less than or equal to 60° (Figure 3). Sector stratification helps explain the pattern of upper extremity exertions over the course of a job cycle.

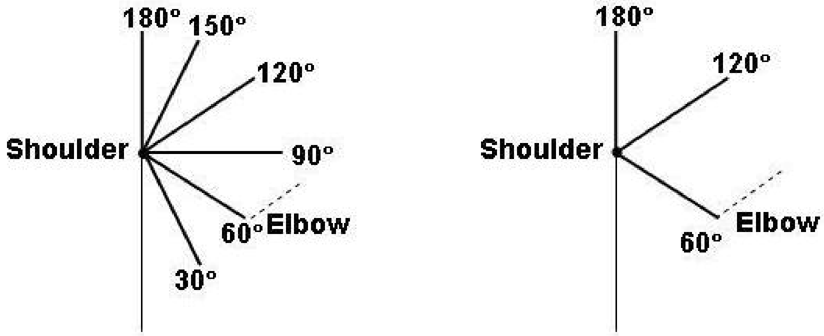

Figure 1. Upper Arm Elevation Sectors

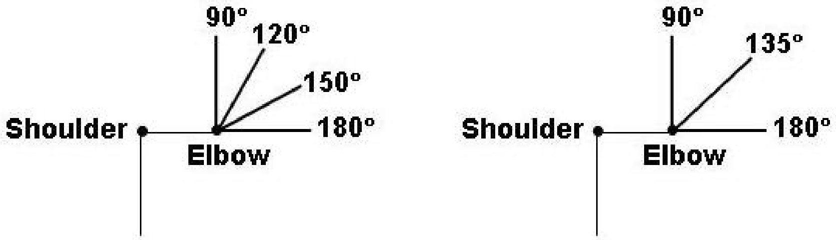

Figure 2. Included Elbow Angle Sectors

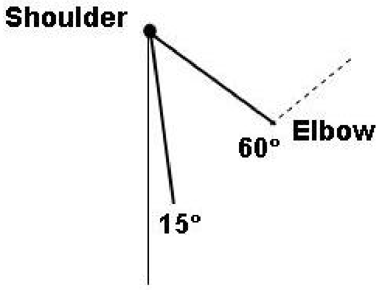

Figure 3. Additional Upper Arm Elevation Sector

The mechanical impingement pathogenesis theory of shoulder disorders presupposes that when the arm passes through approximately 80° abduction or flexion, mechanical impingement of the supraspinatus tendon on the underside of the acromion process occurs, causing contact stress. In order to explore the impingement theory, special consideration was given to both the duration of time the shoulder elevation angle remained between 80° to 100° and the frequency with which the arm passed through that angular range. Hence, a variable representing percent duration of time spent around 80° flexion or abduction was established, as well as a variable that accounted for the frequency the arm passed through that range.

An estimate of the force acting on the shoulder is a valuable resource for understanding the impact of an upper extremity posture on muscular load and subsequent LMF. Upper extremity segment lengths, segment weights, and location of the center of masses of the segments were determined for a 50th percentile male and female based on tabled values (Dempster 1955, Webb Associates 1978). Forearm and hand segments were considered one segment, while the upper arm segment was separate. In order to calculate shoulder moment, reactive forces at the elbow and shoulder had to be determined. Reactive forces at any joint represent both the magnitude of tensile forces in ligaments and muscles that hold the joint together and any shearing or compressive forces acting on surfaces that contact the joint. However, rotational motion must also be considered. The upper extremity segments and load weight, if any, act at a distance away from the supporting shoulder reactive force; thus, a moment at the shoulder is created. Moment is equal to the sum of the forces times their respective perpendicular distances from the lines of action to the point or axis of rotation, and is adjusted for angular offset using the sine function. Figure 4 identifies the moment equation variables and coordinate system. The shoulder moment equation is:

$M_S = -(\cos\theta_S)[(SCM_{UA})(W_{UA}) + (SE)(F_E')] - M_E'$

$M_E = -(\cos\theta_E)[(ECM_{FH})(W_{FH}) + (ECM_H)(W_{LOAD})]$

where,

M_S = shoulder moment

M_E = elbow moment

SCM_{UA} = distance from the shoulder to the center of mass of the upper arm segment

SE = distance from the shoulder to the elbow

ECM_{FH} = distance from the elbow to the center of mass of the forearm-hand segment

ECM_H = distance from the elbow to the center of mass of the load in the hand

W_{UA} = weight of upper arm segment

W_{FH} = weight of forearm-hand segment

W_{LOAD} = weight of hand load

F_E = force at the elbow

θ_S = shoulder angle offset

θ_E = elbow angle offset

A moment represents the strength required of specific muscle actions to maintain posture or impart motion. The moment at the shoulder is greatest when the upper arm is horizontal (90°) and biomechanically negligible at 0° and 180°.

A shoulder moment was calculated for each available set of upper arm elevation angle and included elbow angle data. Values for upper extremity segment lengths, segment weights, and location of the center of masses of the segments were determined for a 50th percentile male and female from a set of tabled values. Shoulder moment was determined both with and without consideration of object weight, if any. Since shoulder moment represents the strength required to maintain upper extremity posture, it is believed that moment is a good representation of the impact of the combination of posture and load.

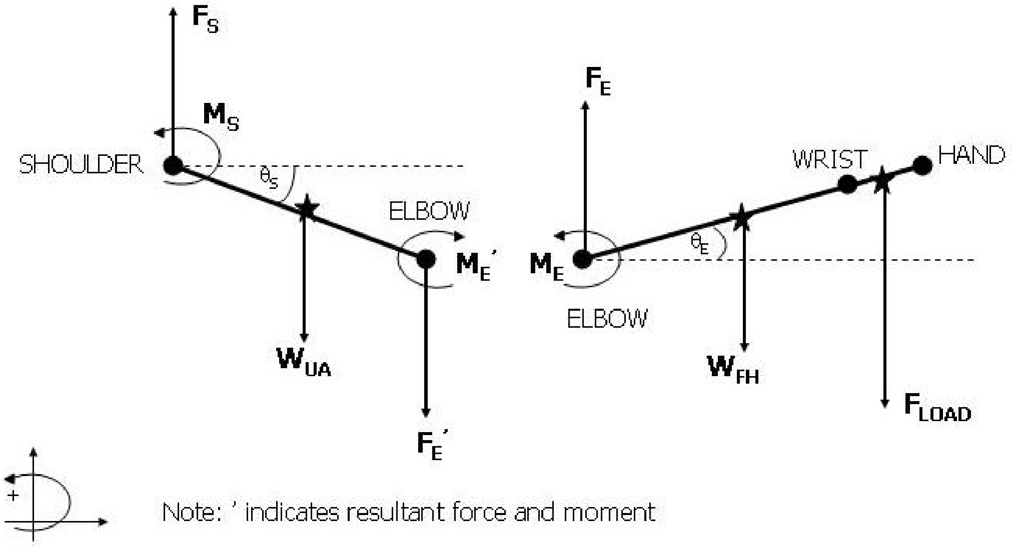

Figure 4. Moment Coordinate System

Morbidity Assessment

After completion of the exposure assessment, injury and illness data records in the form of OSHA 200 logs were reviewed retrospectively over three years (from 1996 to 1998). The OSHA data bordered the time period the videotaping was originally conducted (1998). Recorded data included location, side, and type of disorder. Any occurrence of a shoulder or upper arm entry was recorded separately as an injury or an illness based on OSHA 200 log classification. Injuries were recorded in the logs as sprains or strains. Illnesses were reported as “repetitive motion disorders” of a specified body part in column 7f of the log. A job was considered ‘positive’ if at least one shoulder or upper arm injury or illness was reported in these OSHA logs. A job was considered ‘negative’ if no shoulder or upper arm injuries or illnesses were reported for that job in these OSHA logs. A person with a bilateral condition would be represented as having two separate disorders.

Results

Morbidity Data and Selection of Health Outcome

Fifty-two jobs (by-side) were available for analysis. Thirty-eight (73.1%) of the jobs were positive for shoulder or upper arm injury or illness. Three (5.8% of all jobs) were positive for shoulder or upper arm injury only (no illnesses). Nineteen (36.5% of all jobs) were positive for shoulder or upper arm illness only (no injuries). Sixteen (30.8% of all jobs) were positive for both shoulder or upper arm injury and illness. Fourteen (26.9% of all jobs) were negative for either shoulder or upper arm injury or illness. Figure 5 provides a graphical view of the health outcome distribution in the data set.

Comparisons of exposure data to morbidity were performed using only jobs positive for shoulder or upper arm illness. The 19 positive jobs were compared to the 14 negative jobs for all exposure variables. This route of analysis was pursued for a few reasons. The base rate of positive jobs was 73% when positive was defined as injury or illness. Such a large positive rate could impact the analyses and conceal potential associations. Additionally, there were concerns that entries recorded as injuries were not considered equivalent to those recorded as illnesses in the OSHA logs. Jobs that were positive for shoulder or upper arm injury were described in the OSHA logs as being a “strain/sprain,” which does not correspond with the current research effort of modeling to predict risk of proximal upper extremity *disorders*.

Additionally, it was decided to remove those jobs that were positive for both injury and illness records, since the potential presence of job elements that contributed to risk of injury might bias those job elements that contributed to illness.

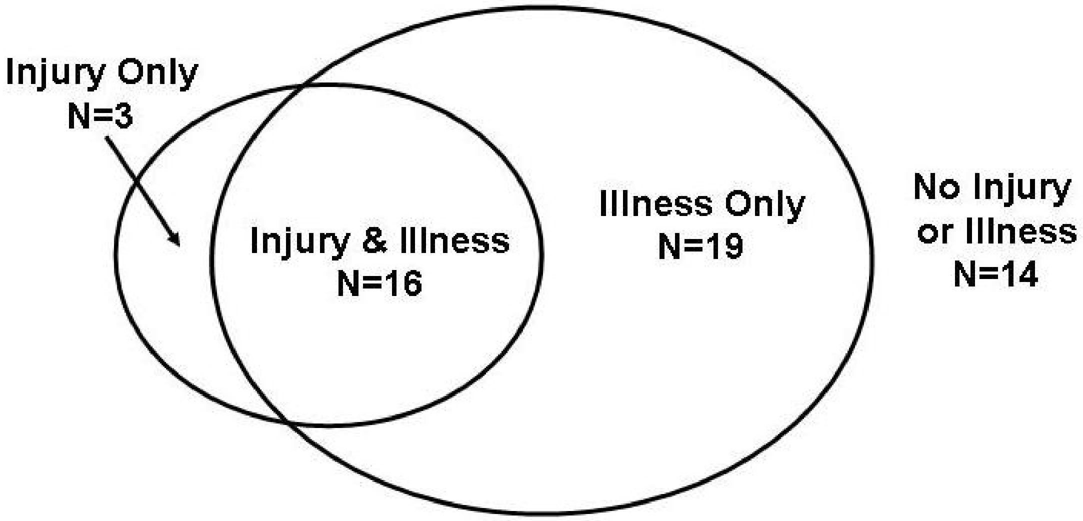

Figure 5. Health Outcome Distribution

In other words, it is expected that the pathologies of proximal upper extremity injury and illness are different. Shoulder or upper arm *injuries* may be linked to overexertion and might be better predicted using existing biomechanical or physiological tools related to manual materials handling. A job may contain elements that contribute to both injury and illness pathology, or either health outcome separately. It was thought that the most informative approach would be to evaluate only the jobs that had health outcomes that most closely aligned with the research effort. Hence, results using jobs defined as positive only for shoulder or upper arm *illness* would provide additional insight into model variable selection and model structure. It may be that injuries, as recorded in the OSHA logs, are traumatic in nature, while illnesses are non-traumatic conditions.

Exposure Data

For the most part, the exposure variables had good representation among the analyzed jobs. Tables II, III, and IV contain the exposure variables, the number of jobs in which each variable was present and absent, and the mean and range of the task variable values among those jobs in which it was present. All upper arm elevation angles were well represented with the exception of upper arm elevation angles greater than 90° to less than or equal to 120°, as well as angles greater than 120° to less than or equal to 150°, in which ranges, only one of the analyzed jobs contained data for each respective variable. Additionally, there were no analyzed jobs that contained data in the upper arm elevation angle range of greater than 150° to less than or equal to 180°. The number of jobs in which the upper arm elevation angle passed through approximately 80° was 16 of 33. All included elbow angle ranges were well represented in the analyzed jobs. Ballistic motion was present in 8 of the 33 jobs. Applied force of any kind was well-represented in the analyzed jobs (26 of 33 jobs), though applied force away from the body was present in only 9 of the 33 jobs. Applied force towards the body was present in 19 of 33 jobs.

Table II. Upper Arm Elevation Angle Exposure Data Summary

UA=Upper Arm Elevation Angle	**Number of Jobs**		**Among Jobs with Variable Present**	
	Present	**Absent**	**Mean**	**Range**
UA ≤ 15°	28	5	37.1%	2.8 - 100%
15° < UA ≤ 60°	32	1	65.2%	17.4 - 100%
60° < UA ≤ 120°	15	18	11.7%	1.1 - 39.4%
120° < UA ≤ 180°	1	32	0.7%	N/A
0° < UA ≤ 30°	33	0	57.7%	14.3 - 100%
30° < UA ≤ 60°	29	4	22.4%	1.4 - 57.9%
60° < UA ≤ 90°	15	18	11.7%	1.1 - 39.4%
90° < UA ≤ 120°	1	32	0.6%	N/A
120° < UA ≤ 150°	1	32	0.7%	N/A
150° < UA ≤ 180°	0	33	N/A	N/A
UA at/near 80°	16	17	10.6%	1.0 - 37.7%

Table III. Included Elbow Angle Exposure Data Summary

EA=Elbow Angle	Number of Jobs		Among Jobs with Variable Present	
	Present	Absent	Mean	Range
EA ≤ 90°	26	7	26.6%	1.3 - 53.4%
90° ≤ EA ≤ 135°	30	3	38.9%	6.1 - 100%
135° < EA ≤ 180°	32	1	45.2%	5 - 100%
90° < EA ≤ 120°	29	4	30.4%	5.6 - 71.4%
120° < EA ≤ 150°	33	0	32.1%	5.3 - 87.0%
150° < EA ≤ 180°	31	2	22.2%	2.7 - 88.9%

Table IV. Task Variable Exposure Data Summary

	Number of Jobs		Frequency Among Jobs with Variable Present	
	Present	Absent	Mean	Range
Ballistic Motion	8	25	19.5/min	5 to 34 per minute
Applied Force: Any	26	7	21.6/min	3 to 57 per minute
Applied Force: Away from Body	9	24	23.0/min	2 to 57 per minute
Applied Force: Toward Body	19	14	18.7/min	3 to 34 per minute
Pass through 80° UA Elevation	16	17	14.8/min	2 to 36 per minute

Statistical Methods and Results

All measured, observed, and estimated exposure variables were compared to shoulder and upper arm illness morbidity data from the OSHA logs. Statistical analyses were performed on the selected data using SPSS® software on a personal computer. Student t-test for use with normally-distributed data was used for comparing the means of the continuous exposure variable data to the morbidity classification. Chi square test for independence was used to determine the relationship between categorical exposure variables and morbidity classification. The intent of the analyses was to look at variables that may influence the pathology of proximal upper extremity disorders. Given that goal and the small sample size of the data set (limited power), it was decided to examine differences in mean values with less emphasis on p-values.

Categorical Data Univariate Analyses

Tables V, VI, VII, and VIII show the distribution of the categorical exposure variables according to morbidity classification and the associated chi-squared value and odds ratio. The data suggested that the presence of applied force towards the body, as well as the presence of applied force in general may impact PUE morbidity ($p < 0.001$). The odds ratio for a job with the presence of applied force towards the body was 19.56 (CI: 3.31 – 115.37).

Table V. Morbidity Contingency Table for the Presence of Applied Force Towards the Body

			Morbidity Classification	
			No Injury/Illness	Illness Only
			1	0
Presence of Applied Force Towards Body		1	16	3
		0	3	11
	Chi-Sq:		0	
	Fisher's Exact:		0	
	OR:		19.56	CI: (3.31 to 115.37)

The odds ratio for a job with the presence of any applied force (towards or away from the body) was 13.5 (CI: 1.39 – 131.32).

Table VI. Morbidity Contingency Table for the Presence of Any Applied Force

		Morbidity Classification	
		No Injury/Illness	**Illness Only**
		1	0
Presence of Any Applied Force	1	18	8
	0	1	6
	Chi-Sq:	0.009	
	Fisher's Exact:	0.026	
	OR:	13.5	CI: (1.39 to 131.32)

There were no significant differences between positive and negative jobs for either the presence of applied force away from the body or the presence of ballistic motion.

Table VII. Morbidity Contingency Table for the Presence of Applied Force Away from the Body

		Morbidity Classification	
		No Injury/Illness	**Illness Only**
		1	0
Presence of Applied Force Away From Body	1	4	5
	0	15	9
	Chi-Sq:	0.35	
	Fisher's Exact:	0.442	
	OR:	0.48	CI: (.10 to 2.27)

Table VIII. Morbidity Contingency Table for the Presence of Ballistic Motion

			Morbidity Classification	
			No Injury/Illness	**Illness Only**
			1	0
Presence of Ballistic Motion		1	6	2
		0	13	12
	Chi-Sq:		0.252	
	Fisher's Exact:		0.416	
	OR:		2.77	CI: (.47 to 16.46)

Continuous Data Univariate Analyses

The data suggested that the number of ballistic motions per minute, the number of applied forces towards the body per minute, the mean and median upper arm elevation angle, the percentage of time the upper arm was elevated between 60° to 90° and 60° to 120°, and the mean shoulder moment may be related to PUE illness morbidity. Univariate comparisons for the continuous exposure variables according to morbidity classification (positive or negative) are presented in Table IX. The number of ballistic motions per minute was higher for positive jobs compared to negative jobs (6.6 vs. 2.2; p=0.20). The number of applied forces towards the body per minute was greater for positive jobs compared to negative jobs (15.2 vs. 4.7; p=0.01). The mean and median upper arm elevation angle over the course of the job cycle were higher for positive jobs compared to negative jobs (24.1° vs. 18.8°; p=0.14) and (21.7° vs. 17.0°; p=0.17), respectively. The percentage of time the upper arm was elevated between 60° to 90° was higher for positive jobs compared to negative jobs (7.7% vs. 2.1%; p=0.08). A similar relationship was found for the percentage of time the upper arm was elevated between 60° to 120°; however, the data set contained no negative jobs where time was spent with the upper arm elevated above 90°, and an almost negligible percentage of time was spent between 90° to 120° in the positive jobs available. The mean shoulder moment (based on data for a 50th percentile male) was greater for positive jobs compared to negative jobs (5.8 Nm vs. 5.3 Nm; p=0.20). There were no other significant differences between positive and negative jobs for any of the other continuous exposure variables.

Table IX. Exposure Variables According to Morbidity Classification

Exposure Variable	"Positive" (n=19) Mean	Std. Dev.	"Negative" (n=14) Mean	Std. Dev.	p-value
Frequency Variables					
Ballistic Motions per Minute	6.6	11.3	2.2	5.8	0.20
Applied Forces per Minute	19.2	11.3	14.1	17.0	0.31
Applied Forces Away from Body per Minute	4.0	11.3	9.4	16.9	0.28
Applied Forces Toward Body per Minute	15.2	11.2	4.7	9.9	0.01
Non-Neutral (UA > 15°) Upper Arm Posture per Minute	20.1	6.4	21.3	12.8	0.71
Upper Arm Elevated through 80° per Minute	7.8	10.3	6.2	9.5	0.65
Upper Extremity Posture Measurements					
Minimum Upper Arm Elevation Angle	-10.2	5.2	-8.0	4.0	0.44
Maximum Upper Arm Elevation Angle	56.8	25.1	47.5	16.7	0.24
Mean Upper Arm Elevation Angle	24.1	11.0	18.8	8.5	0.14
Median Upper Arm Elevation Angle	21.7	10.7	17.0	8.1	0.17
Minimum Included Elbow Angle	81.2	27.9	89.6	35.5	0.45
Maximum Included Elbow Angle	170.1	11.2	169.1	14.0	0.82
Mean Included Elbow Angle	125.8	19.8	130.4	23.3	0.55
Median Included Elbow Angle	124.8	21.2	128.3	24.6	0.67
Upper Arm Time Measurements					
% Duration of Time Spent in Neutral Upper Arm Posture (UA ≤ 15°)	29.4	29.1	34.2	23.1	0.61
% Duration of Time Spent in Upper Arm Posture (15° < UA ≤ 60°)	62.9	28.2	63.9	23.2	0.93
% Duration of Time Spent in Upper Arm Posture (0° < UA ≤ 30°)	53.8	22.3	63.0	20.1	0.23

Table IX Continued

Exposure Variable	**"Positive" (n=19) Mean**	**Std. Dev.**	**"Negative" (n=14) Mean**	**Std. Dev.**	**p-value**
% Duration of Time Spent in Upper Arm Posture ($30^\circ < UA \leq 60^\circ$)	20.3	15.9	18.9	17.3	0.81
% Duration of Time Spent in Upper Arm Posture ($60^\circ < UA \leq 90^\circ$)	7.7	10.6	2.1	4.4	0.08
% Duration of Time Spent in Upper Arm Posture ($90^\circ < UA \leq 120^\circ$)	3.2E-02	0.1	0.0	0.0	0.40
% Duration of Time Spent in Upper Arm Posture ($120^\circ < UA \leq 150^\circ$)	3.7E-02	0.2	0.0	0.0	0.40
% Duration of Time Spent in Upper Arm Posture ($150^\circ < UA \leq 180^\circ$)	0.0	0.0	0.0	0.0	N/A
% Duration of Time Spent in Upper Arm Posture ($0^\circ < UA \leq 60^\circ$)	74.1	24.2	81.9	15.8	0.31
% Duration of Time Spent in Upper Arm Posture ($60^\circ < UA \leq 120^\circ$)	7.7	10.6	2.1	4.4	0.08
% Duration of Time Spent in Upper Arm Posture ($120^\circ < UA \leq 180^\circ$)	3.7E-02	0.2	0.0	0.0	0.40
% Duration of Time Upper Arm Angle at or near 80° Elevation	5.9	9.4	4.0	6.7	0.52
% Duration of Time Upper Arm Angle less than 0° Elevation (Extension)	18.2	24.9	16.0	17.0	0.78
Included Elbow Angle Time Measurements					
% Duration of Time Spent in Included Elbow Angle Posture ($0^\circ < EA \leq 90^\circ$)	23.9	19.2	17.0	17.1	0.29
% Duration of Time Spent in Included Elbow Angle Posture ($90^\circ < EA \leq 120^\circ$)	26.4	12.9	27.1	21.9	0.91
% Duration of Time Spent in Included Elbow Angle Posture ($120^\circ < EA \leq 150^\circ$)	33.3	20.2	30.6	15.8	0.68

Table IX Continued

Exposure Variable	"Positive" (n=19) Mean	Std. Dev.	"Negative" (n=14) Mean	Std. Dev.	p-value
% Duration of Time Spent in Included Elbow Angle Posture (150° < EA ≤ 180°)	17.5	14.9	25.4	27.9	0.30
% Duration of Time Spent in Included Elbow Angle Posture (90° < EA ≤ 135°)	33.2	17.4	38.3	27.5	0.52
% Duration of Time Spent in Included Elbow Angle Posture (135° < EA ≤ 180°)	43.1	27.9	44.7	34.3	0.88
Shoulder Moment Measurements					
Mean Shoulder Moment (for a 50th Percentile Male) [Nm]	5.8	1.1	5.3	1.0	0.20
Mean Shoulder Moment (for a 50th Percentile Female) [Nm]	4.6	0.9	4.2	0.7	0.20
Maximum Shoulder Moment (for a 50th Percentile Male) [Nm]	8.7	1.9	8.3	1.3	0.53
Maximum Shoulder Moment (for a 50th Percentile Female) [Nm]	6.8	1.5	6.5	1.0	0.53

Multivariate Logistic Regression Analysis

A multivariate logistic regression was performed with all continuous and categorical variables found to be influential in the univariate analyses. Variables were entered into the model using backward conditional stepwise selection. A variable was removed from the model if the probability of its score statistic was greater than 0.20. The final logistic model for predicting recorded illness included two variables: (1) the presence of applied force towards the body (x_1) and (2) the percentage of time the upper arm was elevated between 60° and 120° (x_2). The logistic model was:

$$\text{logit}(\pi) = \alpha + \beta_1 x_1 + \beta_2 x_2$$

$$\text{logit}(\pi) = -1.725 + 2.877x_1 + 0.122x_2$$

The estimated odds ratio (e^{β}) for x_1 was 17.769 (95% CI: 2.771 to 113.955); that is, the odds of a job having a recorded illness in the PUE increase multiplicatively by approximately 17.8 when applied force towards the body is present. The estimated odds ratio for x_2 was 1.129 (95% CI: 0.938 to 1.360); that is, the odds of having a recorded illness in the PUE increase multiplicatively by approximately 1.1 for every unit increase in the percentage of time spent in the upper arm elevation range between 60° and 120°. (To clarify further; for example, if a job contained an additional 15% of time in the range of 60° to 120° upper arm elevation, the estimated odds of having a recorded illness in the PUE would be $e^{0.122*15}$ or $e^{1.83} = 6.2$.)

The Hosmer-Lemeshow goodness-of-fit test generated a value of $\chi^2=1.738$ ($p=0.884$), which indicated that the model has no significant lack of fit. Nagerkerke's R^2 for the model was 0.518, indicating that approximately 52% of the variation in recorded illness could be explained by the model. The classification table of observed versus predicted illness can be found in Table X.

Table X. Classification Table of Observed and Predicted Illness

		Predicted Recorded Illness		Percentage Correct
		1	0	
Observed Recorded Illness	1	16	3	84.2%
	0	4	10	71.4%
			Overall Percentage:	78.8%

CHAPTER VI

PROXIMAL UPPER EXTREMITY MODEL DEVELOPMENT

Causation of any symptom or disorder is dependent on the contribution of personal, occupational, non-occupational, and psychosocial factors. All factors are central to understanding the complete picture; however, this research endeavor focused on the contribution of *work*. Hence, the subsequently discussed proposed models to predict risk of proximal upper extremity disorders are based on measurable occupational factors only. Through research on physiology, biomechanics, and epidemiology of the PUE, support for model decisions was found. Such research background is highly relevant.

The proposed model constructs are based on the principles of physiology and biomechanics, and were influenced by epidemiological literature, published experimental observations, and a small-scale, retrospective epidemiological study in a poultry processing plant. Early research consisted of a review of the PUE medical literature, encompassing disciplines such as rheumatology, surgery, and pathology. Because of the interest in predicting rotator cuff disorders, disorder pathology must be understood; hence, proposed models of pathogenesis were derived from the medical literature. Once theories of pathogenesis were established, the next step was to look at what external activities fit in with the models of pathogenesis. That is, it was necessary to determine what biomechanical or physiological stresses occur internally when specific external activities take place. Activities performed long enough or frequently enough might potentially lead to degeneration and initiate the disorder process.

The PUE models have been developed to predict rotator cuff disorders such as tendinitis or tears (partial or complete) in the supraspinatus muscle-tendon unit. The models will not necessarily predict problems such as shoulder myalgia, strains or sprains, or nerve disorders. Stress is composed of physical, environmental, and mental factors. Stress evaluated in conjunction with individual characteristics provides a good construct to model strain, the physiological response to stress. According to Moore and Garg (personal communication), it is possible to describe physiological stress using an index. For some particular form of stress (I), the index can be defined as the ratio of the duration of time I is present, weighted by the magnitude of I, divided by the duration of time I is not present (recovery time) within a job cycle: Index $= (I \cdot \Delta t_i) / (T - \Sigma\Delta t_i)$, where T = cycle time and $\Sigma\Delta t_i$ = time that I is present.

Each index contains variables that represent stress in order to predict strain, as the purpose of the models was to evaluate the job task contribution to physiological strain. Each proposed strain construct is represented by an index. Though desirable in a comprehensive evaluation of a person's risk for PUE disorders, the contribution of individual characteristics such as age, gender, strength capacity, presence of bone anomalies, history of PUE symptoms or disorders, and medical status and history, have not been modeled, nor have psychosocial or non-occupational factors.

Although most physicians are in good agreement regarding what symptoms and physical signs constitute rotator cuff disease, there is some disagreement about the pathogenesis of disorders. To fully explore this divergence of opinion, it was decided to model two theories of pathogenesis, which have been discussed in an earlier chapter: (1) the model of fatigue and (2) the model of impingement.

Model of Fatigue

Muscle or tendon fatigue can be caused by muscle-activated tension, intra-muscular pressure, impaired blood flow, or static load on the muscle-tendon unit. Increased tension magnitude will increase fatigue in the muscle-tendon unit. Similarly, increased duration of tension will increase fatigue in the muscle-tendon unit. Ischemia leads to muscle fatigue which is transmitted to the tendon. Fatigue, or its accumulation, can be decreased or prevented by introducing recovery periods. An increase in duration or frequency of recovery periods tends to decrease muscle-tendon unit fatigue.

Several external activities contribute to the level of PUE muscle-tendon unit tension, including upper arm elevation, an open included elbow angle, arm and object weight, applied force, ballistic motion, speed of work, precision demands, and steady activation of low-threshold motor units. A subset of these activities, including upper arm elevation, included elbow angle, arm weight, and object weight contribute to static shoulder moment. Shoulder moment is proportional to PUE muscle-tendon unit tension. Although the model variables chosen to represent PUE fatigue are not inclusive of every possible occupational influence, they are valid from a physiological and biomechanical perspective and have been identified in the literature as: (1) possible effectors of PUE disorders, or (2) as influential in psychophysical or experimental studies involving the PUE. Additionally, the chosen fatigue model variables have demonstrated some statistical influence when comparing poultry processing jobs with and without record of PUE illness.

From a high-level perspective, the model has been developed in the form of an index where magnitude and duration of PUE tension is leveraged against recovery time; this is then modified by an applied force penalty and a hand load penalty. The variable chosen to represent intensity magnitude is based on prescribed upper arm elevation sectors.

Let proximal upper extremity fatigue be represented by Ψ. Intensity (I) has been defined as the magnitude of tension over time, represented as $\Psi = \int_0^T I \, dt$. Let I_i represent the intensity multiplier associated with the i^{th} intensity level. Let $\%\Delta t_i$ represent the percentage of cycle time spent within the i^{th} intensity level. The percentage of cycle time spent in recovery is represented by $\%\Delta t_R$. An additional ten percent was added to the denominator to account for recovery time not represented by upper arm posture, as well as to keep the index from going to infinity when no recovery based on upper arm posture is present. Let AF represent the multiplier associated with applied force and let L represent the multiplier associated with the hand load.

The proposed fatigue-based PUE Strain Index is:

$$\Psi = \left[\left(\sum_1^i I_i \cdot \%\Delta t_i \right) / \left(\%\Delta t_R + 10\% \right) \right] \cdot AF \cdot L$$

Intensity Multipliers

The proposed intensity sector divisions and associated multipliers are displayed in Table XI. It is to be noted that the verbal anchors used in the description of these sectors are anchors only; that is, they should not be used in isolation to infer associated risk of PUE disorder. Rationalization for the sector divisions will follow. A recovery sector, (I_1), represents the percentage of time the upper arm elevation angle is less than or equal to 15°. The next sector, (I_2), is a moderate level of intensity; it represents the percentage of time the upper arm elevation angle is greater than 15° but less than or equal to 60°. The next sector, (I_3), corresponds to a greater level of intensity; it represents the percentage of time the upper arm elevation angle is greater than 60° but less than or equal to 120°. The remaining sector, (I_4), is also a moderate level of intensity; it represents the percentage of time the upper arm elevation angle is greater than or equal to 120° but less than 180°.

Table XI. Intensity Multipliers

Intensity Sector	Multiplier
I_1: UA $\leq$ 15°	0.0
I_2: 15° < UA $\leq$ 60°	1.5
I_3: 60° < UA $\leq$ 120°	3.0
I_4: UA > 120°	1.5

note: UA=upper arm elevation angle

Results from experimental studies and shoulder biomechanics support the proposed intensity sectors. Upper arm elevation is important because it impacts shoulder moment. Shoulder moment peaks at 90° upper arm elevation and is ‘zero’ at either extreme of upper arm elevation (0° and 180°). In concordance with this, the intensity multiplier is greatest in the range where shoulder moment is greatest. Sigholm et al (1984) saw an increase in supraspinatus fatigue at 45° compared to 0° upper arm elevation; a similar increase in supraspinatus fatigue was seen at 90° compared to 45° upper arm flexion (relationally, an elevation angle in the I_2 sector is more fatiguing than in the I_1 sector; likewise, an elevation angle in the I_3 sector is more fatiguing than in the I_2 sector). Herberts et al (1980) found an increase in supraspinatus fatigue at 90° compared to 45° upper arm abduction (relationally, an elevation angle in the I_3 sector is more fatiguing than in the I_2 sector). Garg et al (1999) found that the maximum acceptable frequency of lift was higher (greater work capacity) for 60° upper arm flexion versus 90° or 120° flexion (relationally, greater work capacity exists in the I_2 sector compared to the I_3 sector). Additionally, the authors found that arm down time (rest time) was greater when the upper arm was repeatedly flexed to 90° or 120° compared to 60° (relationally, greater rest time is required for work in the I_3 sector compared to the I_2 sector). For lift and hold conditions, maximum voluntary contraction was greatest at 0° upper arm flexion, followed by 30°, 60°, and 150° flexion, and was smallest at 90° and 120° flexion (relationally, the greatest strength was seen in the I_1 sector followed by the I_2 and I_4 sectors, while the lowest strength was found in the I_3 sector). The authors found a similar relationship for hold only conditions. It was determined that mean endurance time decreased with an increase in upper arm flexion angle from 30° to 120°, then increased at 150° flexion (relationally, endurance time is shortest in the I_3 sector, and respectively greater in the I_2 and I_4 sectors). Subjects in the Garg et al study generated greater ratings of perceived exertion, fatigue, and pain at 90° and 120° upper arm flexion compared to 60° flexion (relationally, subjective ratings of exertion, fatigue, and pain were higher in the I_3 sector compared to the I_2 sector).

Other studies have demonstrated that the onset of muscle fatigue occurs quickly within the range of 60° to 120° upper arm elevation. Hagberg et al (1981a) saw the occurrence of supraspinatus fatigue in less than fifteen seconds when the upper arm was flexed or abducted to 90°. Kahn and Monod (1984) found signs of PUE fatigue occurred more quickly at 90° compared to 0° upper arm elevation.

Blood flow impedance, or resistance to flow, has been demonstrated in the range of 60° to 120° upper arm elevation. Jarvholm et al (1988b) found impedance in the supraspinatus at 90° upper arm flexion and abduction with no additional hand load. Addition of a hand load generated even greater impedance. Jarvholm et al (1991b) studied the effect of arm support on supraspinatus impedance for a welding simulation that required 60° upper arm flexion and a 3.0 [lb] tool. It was found that even with arm supports, the supraspinatus blood flow was impeded. Blood flow impedance has been demonstrated at upper arm elevation angles less than 60° and greater than 120°. Jarvholm et al (1988b) found impedance in the supraspinatus at 30° upper arm abduction, as well as at 135° abduction, though comparatively, lesser impedance was found at 90° abduction.

In addition to the support from experimental studies, evidence was found in multivariate logistic regression analysis. The percentage of time spent with the upper arm elevation angle between 60° to 120° was found to contribute to the prediction of recorded illness ($p < 0.2$).

Applied Force Multipliers

The proposed applied force multipliers, seen in Table XII, were determined based on whether the force was applied towards or away from the body and whether the force was a ballistic one. Univariate statistical analyses identified that applied force in general and applied force towards the body were associated with recorded illness. However, multivariate logistic regression (with all univariate variables that were statistically significant entered) demonstrated that only applied force towards the body was a contributor to the prediction of recorded illness ($p < 0.01$). Preliminary univariate analyses indicated that the number of ballistic motions per minute may play a role in morbidity classification.

Table XII. Applied Force Multipliers

Applied Force Multipliers	> 50% Towards Body	< 50% Towards Body
> 50% Ballistic	2.0	1.25
< 50% Ballistic	1.5	1.0

Load Multipliers

The hand load multipliers, seen in Table XIII, are both task duration and load dependent. The load multipliers and categories were generated primarily from research by Garg et al (1999). The authors showed that a 4 [lb] tool weight generated significantly higher ratings of perceived exertion, fatigue, and pain than a 2 [lb] or 1 [lb] weight, regardless of duration held. Subjects estimated they could not perform work for greater than two hours in 90° or 120° flexion when hand tool weight was greater than or equal to 2 [lb]. In contrast, subjects estimated they could perform work for eight hours with a 1 [lb] hand weight. The multiplier separation based on percentage of time spent holding a load was chosen as 25% because two hours is 25% of an eight hour workday.

Other research supports the load multiplier divisions as well. Jarvholm et al (1988b) found that an increase in 2 [kg] (4.4 [lb]) of hand weight generated increases in supraspinatus blood flow impedance throughout all levels of upper arm elevation. The value needed to equate the impedance in mmHg found at 30° abduction without a hand load (81 mmHg) with the impedance found at 30° abduction with a 2 [kg] hand load (138 mmHg) was calculated to be 1.7 (almost twice the measured impedance).

Table XIII. Load Multipliers

Hand Load Multipliers	$\geq$ 25% Task Duration	< 25% Task Duration
$L \leq 2$ [lb]	1.0	1.0
$2 < L < 4$ [lb]	1.5	1.0
$L \geq 4$ [lb]	2.0	1.25

note: L = Load

Using the Fatigue Model

Use of the fatigue model may be best demonstrated with an example: A worker spends 25% of his time with an upper arm elevation angle less than or equal to 15°, 65% of the time with the arm between 15° and 60°, and 10% of the time between 60° and 120°. Less than half of the applied forces are towards the body, but greater than half are ballistic in nature. The worker holds a tool that weighs 2.5 [lb] when performing tasks that occur less than 10% of the time. An index can be calculated using the fatigue-based model:

$$\Psi = \{[(0.0)(0.25) + (1.5)(0.65) + (3.0)(0.10)]/(0.25 + 0.10)\}(1.25)(1.0) = 4.5$$

Validation of the Fatigue Model Using Epidemiological Data

Among positive job categories, the Fatigue Model scores ranged from 0 to 41.85 with a mean of 10.45. The negative job scores ranged from 0.53 to 15, with a mean of 4.71. The distribution of positive and negative jobs among index scores is shown in Figure 6. Inspection of the distribution suggests that a score near 4.0 best discriminates between negative and positive jobs. In addition to visually noting the score that differentiates a negative and positive job, a logistic regression was performed with the fatigue index score as the independent variable and recorded illness as the dependent variable:

$$\text{logit}(\pi) = \alpha + \beta x$$

$$\text{logit}(\pi) = -0.337 + 0.093x$$

The model demonstrated that fatigue index score was a good predictor of recorded illness ($p=0.118$). The value at which either outcome (positive or negative job) has a 50% chance of occurring (the median effective level) is at $x = -\alpha/\beta$. The median effective level for this regression equation is $x = -[(-0.337)/0.093] = 3.6$. This value is compatible with the index score determined as a separator based on the histogram of fatigue index score distribution.

Based on the aforementioned evaluations, an index value of 4.0 was chosen as the threshold for determining whether a job was considered "hazardous" (greater than or equal to 4.0) or "safe" (less than 4.0). A "hazardous" job represents a job that is predicted to have an adverse effect in the PUE for the workers performing the job. In contrast, a "safe" job represents one which is not predicted to adversely affect workers performing the job.

The formulas for measures of predictive validity, as well as a generic contingency table are provided in Figure 7. The contingency table for the fatigue model is presented in Table XIV. Eighteen (55%) jobs were predicted to be "hazardous," while fifteen (45%) were predicted to be "safe." The index scores for the "hazardous" jobs ranged from 4.4 to 41.9, with a mean of 13.2. The index scores for the "safe" jobs ranged from 0 to 3.5, with a mean of 1.8. Of the 18 jobs predicted to be "hazardous," 14 were true positives (predicted to be "hazardous" when they were positive), while 4 were false positives (predicted to be "hazardous" when they were negative). Of the 15 jobs predicted to be "safe," 10 were true negatives (predicted to be "safe" when they negative), while 5 were false negatives (predicted to be "safe" when they were positive).

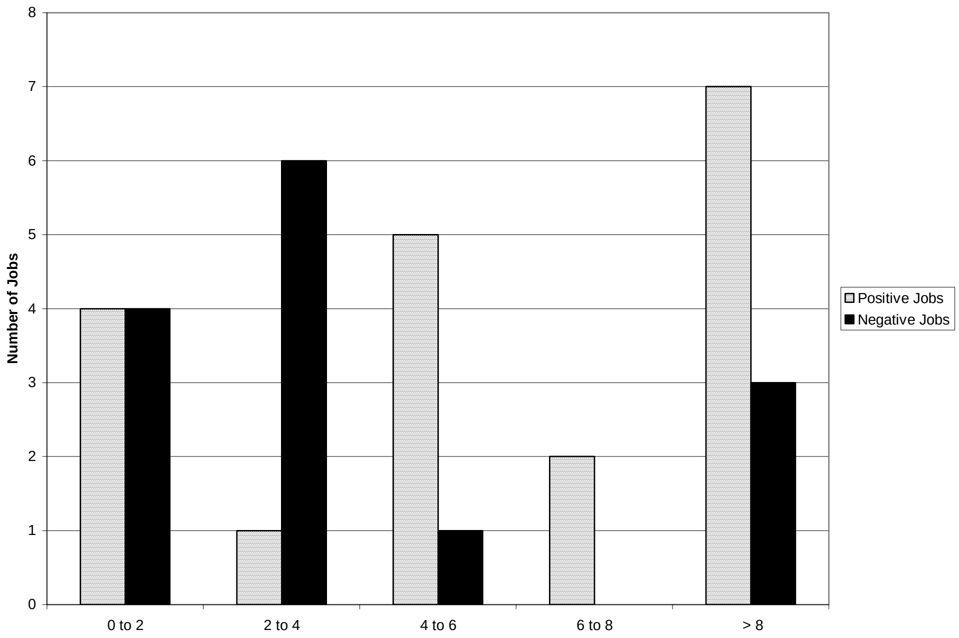

Figure 6. Fatigue Model Job Distribution

a	b
c	d

OR=ad/bc

Sensitivity: a/(a+c)
Specificity: d/(b+d)
Positive Predictive Value: a/(a+b)
Negative Predictive Value: d/(c+d)
note: OR=odds ratio

Figure 7. General Contingency Table

Table XIV. Morbidity Contingency Table for Fatigue Model Prediction

Fatigue Construct		**Morbidity Classification**	
		Positive	**Negative**
		1	0
Hazardous	1	14	4
Safe	0	5	10

OR=7

Haz/Pos	14	True +
Haz/Neg	4	False -
Saf/Pos	5	False +
Saf/Neg	10	True -

OR =7 (p = .014)
Sensitvity: 14/(14+5)=0.74
Specificity: 10/(4+10)=0.71
Positive Predictive Value: 14/(14+4)=0.78
Negative Predictive Value: 10/(10+5)=0.67

One of the four jobs that were falsely predicted to be “hazardous” had a fatigue index value of 4.6, which is close to the threshold between “hazardous” and “safe.” For this job, approximately 95% of the time was spent with the upper arm elevated less than or equal to 60° (35.5% of the time was spent with the arm elevated less than or equal to 15°, while 59.4% of the time was spent in the range greater than 15° but less than or equal to 60°). The other three jobs that were falsely predicted to be “hazardous” had index values between 11 and 15. For these three jobs, 95% to 100% of the upper arm activity was spent in the range of greater than 15° but less than or equal to 60°, leaving a recovery time deficit. This lack of defined recovery time contributed to their classification as “hazardous.” It might be that the penalty for the second Intensity sector (upper arm elevation greater than 15° to less than or equal to 60°) is too high. In 3 of the 5 jobs that were falsely predicted to be “safe,” greater than two-thirds of the cycle time was spent with upper arm elevation angle less than or equal to 15° (recovery sector). For the remaining 2 jobs, about 40% to 60% of the cycle time was spent with upper arm elevation angle less than or equal to 15°.

The predictive validity of the Fatigue-Based PUE Index was represented by sensitivity, specificity, positive predictive value, and negative predictive value. Sensitivity, (a measure of the probability of correctly identifying a case), for the fatigue model was 0.74. Specificity, (a measure of the probability of correctly identifying a non-case), was 0.71. Positive predictive value was 0.78. Negative predictive value was 0.67. The odds ratio was 7.0 (95% CI: 1.49, 32.82; p=0.014). That is, the odds that a "hazardous" job was a true positive were 7.0 times the odds that a "safe" job would be classified as a true positive.

Model of Compressive Load

Some factors may produce or contribute to a compressive load in the PUE. The supraspinatus tendon and other rotator cuff tendons may become impinged under the coracoacromial ligament or the underside of the acromion. The subacromial bursa may become impinged similarly. Additionally, adduction with neutral rotation may compress the underside of the supraspinatus tendon; however, medical reports of degeneration on the underside of the supraspinatus tendon are rare. Thus, the contribution of adduction with neutral rotation will not be considered in the model of compressive load.

Measurable external activities can contribute to impingement of the supraspinatus tendon or subacromial bursa, including the frequency the upper arm passes through approximately 80° of elevation and the duration of time the upper arm spends in that approximate region (between 80° to 100° elevation). Those external activities have been identified in the literature as potentially influential in the development of PUE disorders.

Model Elements

From a high-level perspective, the model has been developed in the form of an index where frequency and duration of compressive load is leveraged against recovery time. Let Φ represent the PUE compressive load index. Let I_C represent the intensity, or frequency of compressive load and Δt_C represent the duration of compressive load (number of times upper arm passes through approximately 80° and the duration of time spent around 80°, respectively). Recovery time is represented by $(T - \Delta t_C)$ (percentage of time not spent around 80° of upper arm elevation).

The proposed compressive load-based PUE Strain Index is:

$$\Phi = (I_C \bullet \Delta t_C) / (T - \Delta t_C)$$

Using the Compressive Load Model

Model usage may be best demonstrated with an example: A worker elevates his upper arm through the arc of 80° five times over the course of a 0.9 minute job cycle. He holds his arm at approximately 80° for 0.4 minutes of the job cycle, hence his recovery time is 0.5 minutes for the job cycle. An index can be calculated using the compressive load-based model:

$$\Phi = [(5)(0.4)]/(0.5) = 4$$

Validation of the Compressive Load Model Using Epidemiological Data

Among positive job categories, the Compressive Load-Based PUE Index scores ranged from 0 to 2.42 with a mean of 0.32. The negative job scores ranged from 0 to 1.49, with a mean of 0.21. The distribution of positive and negative jobs among compressive load index scores is shown in Figure 8. Visual assessment of the distribution failed to reveal any logical cutoff that clearly delineates between positive and negative jobs. However, a logistic model may provide rational justification for a cutoff. A logistic regression was executed with the compressive load index score as the independent variable and recorded illness as the dependent variable:

$$\text{logit}(\pi) = \alpha + \beta x$$

$$\text{logit}(\pi) = 0.188 + 0.447x$$

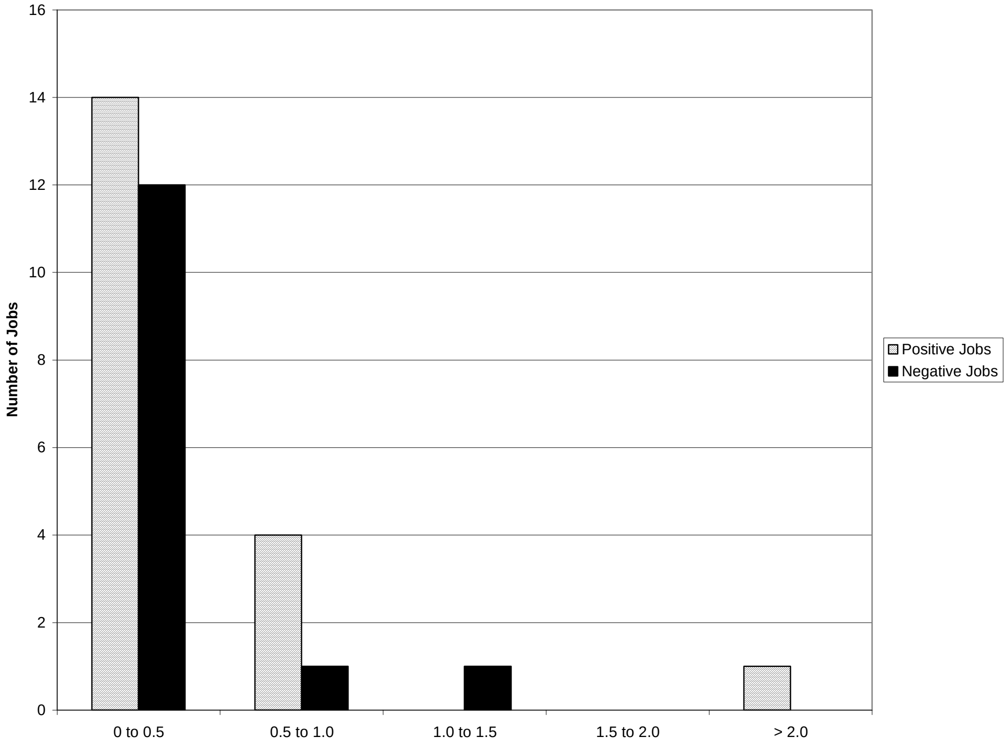

Figure 8. Compressive Load Model Job Distribution

The model did not demonstrate that compressive load index score was a good predictor of recorded illness (p=0.554). No conclusions could be drawn regarding a median effective level that could serve as a delineator for negative and positive jobs.

The compressive load index value of 0.5 was arbitrarily chosen as the threshold for determining whether a job was considered "hazardous" (greater than or equal to 0.5) or "safe" (less than 0.5). A "hazardous" job represents a job that is predicted to have an adverse effect in the PUE for the workers performing the job. In contrast, a "safe" job represents one which is not predicted to adversely affect workers performing the job. The contingency table for the compressive load model is presented in Table XV. Seven (21%) jobs were predicted to be "hazardous," while twenty-six

(79%) were predicted to be “safe.” The index scores for the “hazardous” jobs ranged from 0.54 to 2.42, with a mean of 1.08. The index scores for the “safe” jobs ranged from 0 to 0.48, with a mean of 0.06. Of the 7 jobs predicted to be “hazardous,” 5 were true positives (predicted to be “hazardous” when they were positive), while 2 were false positives (predicted to be “hazardous” when they were negative). Of the 26 jobs predicted to be “safe,” 12 were true negatives (predicted to be “safe” when they were negative), while 14 were false negatives (predicted to be “safe” when they were positive). No consistent explanation for the misclassification could be determined.

Table XV. Morbidity Contingency Table for Compressive Load Model Prediction

Compressive Load Construct		Morbidity Classification	
		Positive	**Negative**
		1	0
Hazardous	1	5	14
Safe	0	2	12

OR=2.1 (p = 0.410)

Haz/Pos	5	True +
Haz/Neg	14	False -
Saf/Pos	2	False +
Saf/Neg	12	True -

Sensitvity: 5/(5+2)=0.71
Specificity: 12/(14+12)=0.46
Positive Predictive Value: 5/(5+14)=0.26
Negative Predictive Value: 12/(2+12)=0.86

The predictive validity of the compressive load index was represented by sensitivity, specificity, positive predictive value, and negative predictive value. Sensitivity for the compressive load-based model was 0.26, while specificity was 0.86. Positive predictive value was 0.71. Negative predictive value was 0.46. In other words, this model was pretty good at classifying a job as “hazardous” when it was positive; however, it was not a good predictor of safe jobs. In fact, more positive jobs were predicted as “safe” than negative jobs. No significant odds ratio was determined (OR=2.1, p=0.410).

A description of the exposure data and its relationship to job morbidity and predicted risk is relevant. Table XVI summarizes the task variable values across jobs, morbidity, and predicted risk using both the Fatigue and Compressive Load models.

Table XVI. Exposure Data, Morbidity, and Predicted Risk

	Percentage of Time Upper Arm (UA) Elevation in Sector					Applied Force	Applied Force Towards the Body	Applied Force Away from the Body	Ballistic Motion			Morbidity	Fatigue Index Score	Fatigue Index Classification	Fatigue Index Classification	Compressive Load Index Score	Compressive Load Index Classification	Compressive Load Index Classification
Job	UA ≤ 15°	15° < UA ≤ 60°	60° < UA ≤ 120°	UA > 120°	UA ~80°	Frequency [per min]	Frequency [per min]	Frequency [per min]	Frequency [per min]	Frequency UA Pass through 80°	Load Weight [lb]	1=Positive; 0=Negative	1=Hazardous; 0=Safe	X=False Positive	X=False Negative	1=Hazardous; 0=Safe	X=False Positive	X=False Negative
1	35.2	64.8	0.0	0.0	0.0	13	13	0	0	0	< 2	0	0			0		
2	68.2	31.8	0.0	0.0	0.0	0	0	0	0	0	< 2	0	0			0		
3	16.7	83.3	0.0	0.0	0.0	8	8	0	0	0	< 2	1	1			0		X
4	35.5	59.4	5.2	0.0	6.5	24	24	0	12	12	< 2	0	1	X		0		
5	0.0	100.0	0.0	0.0	0.0	12	12	0	0	0	< 2	1	1			0		X
6	100.0	0.0	0.0	0.0	13.8	0	0	0	0	21	< 2	1	0		X	1		
7	82.6	17.4	0.0	0.0	0.0	30	30	0	0	0	< 2	1	0		X	0		X
8	0.0	60.7	39.4	0.0	37.7	14	14	0	14	14	< 2	1	1			1		
9	66.7	30.3	3.0	0.0	8.2	29	0	29	0	22	< 2	1	0		X	1		
10	40.0	60.0	0.0	0.0	1.0	0	0	0	0	4	< 2	0	0			0		
11	27.6	58.1	14.4	0.0	23.0	57	0	57	19	19	< 2	0	0			1	X	
12	18.7	70.1	11.1	0.0	0.0	42	0	42	34	0	< 2	1	1			0		X
13	8.4	85.1	6.7	0.0	5.0	24	24	0	24	12	< 2	1	1			0		X
14	39.5	48.3	12.2	0.0	11.0	24	24	0	24	36	< 2	1	1			1		
15	0.0	100.0	0.0	0.0	0.0	29	29	0	24	0	< 2	1	1			0		X
16	12.5	58.3	29.2	0.0	17.0	34	34	0	5	19	< 2	1	1			1		
17	58.4	29.1	12.5	0.0	0.0	15	15	0	0	0	< 2	1	0		X	0		X
18	33.2	66.8	0.0	0.0	0.0	0	0	0	0	0	< 2	0	0			0		
19	23.2	75.8	1.1	0.0	11.0	0	0	0	0	22	< 2	0	0			1	X	
20	17.2	73.0	9.8	0.0	4.8	16	16	0	0	9	< 2	1	1			0		X
21	43.9	48.0	7.5	0.7	3.5	18	18	0	0	6	< 2	1	0		X	0		X
22	29.9	60.5	9.7	0.0	11.0	5	3	2	0	9	< 2	1	1			0		X
23	13.9	86.1	0.0	0.0	0.0	6	6	0	0	0	< 2	1	1			0		X
24	24.1	75.9	0.0	0.0	1.0	7	4	3	0	2	< 2	1	1			0		X
25	31.8	59.1	9.1	0.0	8.7	26	0	26	0	26	< 2	0	0			0		
26	0.0	94.7	5.3	0.0	0.0	26	26	0	0	0	< 2	1	1			0		X
27	26.4	73.6	0.0	0.0	0.0	26	26	0	0	0	< 2	1	1			0		X
28	0.0	100.0	0.0	0.0	0.0	0	0	0	0	0	< 2	0	1	X		0		
29	71.4	28.6	0.0	0.0	0.0	0	0	0	0	0	< 2	0	0			0		
30	2.8	97.2	0.0	0.0	5.8	3	0	3	0	3	< 2	0	1	X		0		
31	36.1	63.9	0.0	0.0	0.0	23	0	23	0	0	< 2	0	0			0		
32	5.2	94.8	0.0	0.0	0.0	29	29	0	0	0	< 2	0	1	X		0		
33	69.1	30.9	0.0	0.0	0.0	22	0	22	0	0	< 2	0	0			0		

CHAPTER VII
DISCUSSION AND CONCLUSION

In this small-scale epidemiological effort, the fatigue index proved to be a good predictor of recorded illness in the PUE; that is, it appears to fit the data better than the compressive load index. Limitations in the predictive ability of the fatigue index may be due to an incomplete understanding of the pathogenesis of PUE disorders. That is not to say that the compressive load index should be discarded or is useless. In a larger data set with more job variation and more specific instances of frequent overhead work, the compressive load index or a similar effort might be an improved predictor. One must also consider the health outcome definition; that is, a different health outcome definition, such as recorded injuries, might better align with the compressive load theory of pathogenesis. In fact, as an exploratory effort, the three injury-only jobs were compared with the fourteen non-injury or illness jobs. Two variables: (1) the frequency the arm passed through 80° upper arm elevation and (2) the duration of time spent around approximately 80°, showed a suggestion of a relationship to recorded injury in univariate analyses (compared to the significance levels achieved when comparing recorded illnesses to no injury/illness). However, because of the extremely small sample size, this vein of effort was not pursued further. An alternate perspective would be to consider only bilateral disorders, or a non-dichotomous health outcome, such as specific disorders (if such medical records were available for analysis), incidence rates, or prevalence rates.

Future data sets would ideally include one or more industries with many more jobs, a larger variation in the upper arm pattern of postural activity, and a greater variation in work-rest cycles. The impact of speed of work, vibration, and ambient temperature should also be considered if such information were available. If the method were to be evaluated prospectively, data on the presence of PUE pain at study onset would be important and ratings of perceived exertion could provide a quantitative measure of force. It could be determined whether the current applied force and load multiplier sets sufficiently explained the impact of force and load.

The PUE index is a work-in-progress with limitations. It depends on quantitative measurement of task variables, and is job-specific, not person-specific. Exclusion of some potential influential factors is, of course, a limitation of the model. However, since many contributing factors are not easily measurable or are subjective by definition, the reluctance to apply them is warranted. It is true that some factors are likely relevant to the development of proximal upper extremity problems, such as a person's age or the presence of bone spurs or other anatomical anomalies and rarities. It is also true that non-occupational factors could play a significant role in the pathogenesis of PUE disorders. Non-occupational interests with PUE patterns of postural activity similar to, or with greater duration than at work, almost assuredly would affect a person's disposition for PUE disorders, yet non-work activities are not feasibly or consistently measurable. A questionnaire that elicits whether a certain non-work activity is present or absent, or even a general inquiry such as whether the responder regularly has leisure hobbies, provide limited added value to an objective measure of stress on the body. No evidence of consistent agreement has been established that personal factors such as history of illness, obesity, smoking, or diabetes are relevant to the pathogenesis of PUE disorders. Similarly, evidence of psychosocial contributions to PUE disorders is contradictory. Even if an accepted consensus was determined regarding psychosocial influences, the health outcome definitions often chosen in such studies could questionably be applied to this proposed model. Nonetheless, future research efforts should endeavor to include measurable factors apart from occupational demands. Test-retest repeatability and inter- or intra-rater reliability have not yet been evaluated. Though no multiple-task jobs were present in the epidemiological portion of the research, the method does provide the opportunity to evaluate a job with multiple tasks.

It may be that age-related degeneration in the proximal upper extremity is the primary contributor to the development of a PUE disorder or injury. A person's medical history and work history could play a significant role in how much of a disorder can be explained by occupational tasks. This research effort has added to the body of knowledge on the effect occupational tasks have on the development of PUE disorders.

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