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Abstract

The purpose of this study was to analyze the ergonomic-based risk factors which were present for workers using the wig-wag machine at Company XYZ and then to assess the factors' contributions to work-related musculoskeletal disorders (WMSDs). Several goals were developed to achieve the purpose of this research. Ergonomic risk assessment tools such as the Rapid Entire Body Assessment (REBA) and the ergonomic task analysis worksheet were utilized to assist in the identification of such risk factors. The evaluation of this study included an employee pain/discomfort symptom survey and a review of the company's OSHA 300 log to pinpoint areas of concern where MSDs may exist or develop. To promote the evaluation of this, anthropometric values/data examined to ensure an optimal fit between the workers and the wig-wag machine design. The results of the data collection in this study identify that various ergonomic-based risk factors are associated with the current wig-wag process including awkward postures, high repetition and excessive work durations which are of great concern in this case. Several engineering and administrative-based controls were offered which would help to eliminate/reduce the presence of the ergonomic-based risk factors and thus lower the potential of developing WMSDs among the wig-wag operators.

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Chapter I: Introduction

Ergonomics can be defined as a multidisciplinary scientific study that attempts to design workplaces, tasks, equipment and products based on characteristics of people's limitations and capabilities (Chengalur, Rodger, & Bernard, 2004). The word "ergonomics" is derived from two Greek words: ergon, "to work," and nomikos, "natural law" (Tayyari & Smith, 1997, p. 1). Terminology concerning ergonomics includes human factors, human engineering, biomechanics, engineering, physiology and work physiology (Tayyari & Smith, 1997).

The multidisciplinary science of ergonomics seeks to achieve the optimal correlation between the users and the work environment by focusing on the interaction or the interface between these two elements (Tayyari & Smith, 1997). Ergonomics considers the human being as an integrated aspect of the design process to produce goods and services, rather than people as a secondary consideration (Bridger, 2009). Therefore, one of the main ergonomic objectives is to adapt or design work, jobs, and equipment to be appropriate for people and thus consider their limitations and capabilities, rather than adapting people to the work environment. This approach helps to eliminate or reduce unnecessary physical stress and contributes to various benefits such as improving safety and health, enhancing productivity and quality, and increasing employee satisfaction (Chengalur et al., 2004).

Since ergonomics is a multidisciplinary science, this requires ergonomists to be knowledgeable in a multitude of disciplines including engineering, technology, physics and mathematics, anthropometry, physiology, biology and epidemiology (Tayyari & Smith, 1997). Ergonomics focuses on various work-related risk factors such as repetitive motion, extreme forces, awkward posture, temperature extremes, excessive exposure time, noise, vibration and substandard lighting. These ergonomic risk factors can be identified utilizing a varity of ergonomic risk assessment tools. Controlling risk factors enables ergonomists to reduce or eliminate injuries, illnesses and disorders before they contribute to serious long-term musculoskeletal disorders (MSDs) (Chengalur et al., 2004).

MSDs can be defined as any injury or disorder that affects muscles, joints, ligaments, nerves, tendons, spinal disk, and cartilage. Examples of MSDs include carpal tunnel syndrome, trigger finger, vibration syndrome and thoracic outlet syndrome (Bridger, 2009). Usually MSDs occur if the job's physical demands exceed the physical capacities or limitations of the human body. Over time MSDs become cumulative trauma disorder (CTDs), the result of accumulation of stressors or overuse of the same musculoskeletal components (Tayyari & Smith, 1997). The issue of work-related musculoskeletal disorders (WMSDs) is enormous as such illnesses affect not only human health, but place a massive burden on the overall economy. These disorders are often associated with one or more ergonomic risk factors including repetition, force, duration, posture and stress (Bridger, 2009). According to Meinhardt (2003), MSDs affect 1.8 million employees every year and constitute $1 out of $3 spent on worker compensation in the United States. In 2010, the Bureau of Labor Statistics (BLS) indicated that 29% of all workplace injuries and illnesses that require time away from work are a direct consequence of poor ergonomics. These work-related disorders are considered the most common and costly which are preventable and require serious consideration (Meinhardt, 2003).

Company XYZ is an independent and refurbished mixing facility founded in 1997 which is located in Eau Claire, Wisconsin. This plant mainly produces rubber-based materials and then ships this product to other manufacturers, such as tire producers. Approximately 123 employees work five days per week in the facility to produce an average of sixteen bins of rubber/polymer a day, with the average bin weighting 1000 pounds. These bins are constructed from galvanized steel or aluminum with dimensions of 39" high, 60" in length and 46" wide.

The process of manufacturing rubber in Company XYZ's facility consists of multiple stages, with the number of stages depending on the consumer's specifications. During the final stages of production, the company utilizes a machine called a wig-wag to load the heavy rubber strips in the bins. Observation of this process indicates that four wig-wag operators perform this task while standing for a considerable duration of time. The wig-wag operators receive the polymer strips from the upper part of the machine and load them in bins which are located at a lower level. This process forces the employees to repeatedly reach upward, forward and flex the spine, as though someone was attempting to reach his/her toes while standing. It is believed that all wig-wag operators experience repetitive motions in the course of performing their duties. Each wig-wag operator works an average of five to six hours performing this task during an eight hour shift, and it takes an average of 45 minutes to load one bin. The average age of the wig-wag operators is 49 years. The facility's safety director indicated that several wig-wag operators have expressed concerns regarding the ergonomic risk factors such as awkward postures, repetitive motion, reaching, spine flexion and prolonged work durations. Therefore, the observed presence of ergonomic-based risk factors for employees who work on the wig-wag process at Company XYZ is placing the respective individuals at risk of developing various types of musculoskeletal disorders.

Purpose of the Study

The purpose of this study is to analyze the ergonomic-based risk factors which are present for workers using the wig-wag machine at Company XYZ.

Goals of the Study

The goals of this study were to:

- Perform an ergonomic workstation analysis utilizing the Rapid Entire Body Assessment (REBA).

- Quantify the extent of posture, force, repetition, duration, and temperature extremes with an ergonomic task analysis worksheet.
- Perform a review of the company's OSHA 300 log to determine the frequency of the ergonomic-based risk factor which relate to the wig-wag process.
- Administer an employee symptom survey to quantify the extent of pain or discomfort that employees are experiencing.
- Conduct an anthropometric study to assess with the intention of accommodating the smallest (5^{th}) and the largest (95^{th}) percentiles of the population to ensure and achieve optimal fit between the wig-wag operators and the machine.

Background and Significance

Since the observed ergonomic risk factors associated with the wig-wag machine place the operators at the Company XYZ at risk of developing WMSDs, the need to conduct an ergonomic assessment is significant. This analysis attempts to identify ergonomic risk factors and their root causes in order to determine the needed controls to eliminate or reduce the risk to an acceptable level. While the likely presence of observed ergonomic risk factors has not yet caused recordable injuries/illnesses, as the facility's safety director mentioned, over time they are likely to create undesirable consequences and losses. These consequences may contribute to direct losses of increased worker compensation and medical care costs, and indirect costs associated with lost worker time, employee replacement through hiring, training and concomitant quality and productivity downgrades. According to the facility safety director, the total cost associated with one shoulder injury could easily surpass $20,000, and the total cost associated with one back injury could easily exceed $54,200.

Alternatively, proactive measures to address the ergonomic problems of the wig-wag operators to prevent human injury or illness and the associated costs, could provide Company XYZ with many benefits. These benefits include:

- Reducing employee absenteeism and job turnover
- Reducing the costs of insurance premiums
- Reducing the probability and likelihood of accidents
- Eliminating or minimizing the risk of developing a WMSD injury or illness
- Avoiding direct and indirect costs associated with a WMSD injury or illness
- Enhancing employees comfort and satisfaction
- Promoting productivity, quality, profitability and overall performance
- Complying with labor regulations, thereby avoiding costly citations

Assumptions of the Study

There are three assumptions pertaining to this study which include:

- The level/types of ergonomic risks that the wig-wag machine operators are exposed to are dependent upon their individual size/shape as well as preferred work practices.
- All information, data and answers provided by Company XYZ are accurate and complete.
- All the wig-wag machine operators perform the job consistently whether they are observed or not.

Limitations of the Study

This study is limited to Company XYZ's wig-wag process during the frame time of October through December, 2012.

Definition of Terms

Administrative control. This type of control includes the practices, policies and requirements established at the administrative level to promote safety and health of the workplace. Examples of administrative control are job training, job rotation and job task enlargement (Bridge, 2009).

Anthropometry. "The study of the dimensions and certain other physical characteristics of the human body such as weight, volumes, centers of gravity, internal properties of body segments, and strength of various muscle groups" (Tayyari & Smith, 1997, p. 41). Ergonomic studies attempt to use collected anthropometry data to design workplace, product or equipment appropriate for a particular population.

Cumulative trauma disorders (CTDs). CTDs can be defined as the musculoskeletal injuries and illnesses that occur or develop from the repeated use of the same musculoskeletal elements (repeated microtrauma). CTDs are not a consequence of accident or sudden break in the musculoskeletal components (Taylor & Francis, 1988).

Cycle time. Refers to the time interval needed to complete a sequence of events. It also describes time needed to complete single or multiple operations in a repetitive task (Chengalur et al., 2004).

Engineering control. Often the most reliable and effective control used in the risk assessment process, it directly eliminates or mitigates the employee's exposure to risk to an acceptable level. Examples of engineering control include modification to tools design and the use of mechanical hoist to lift objects (Chengalur et al., 2004).

Ergonomics. It can be defined as a multidisciplinary scientific study that attempts to design workplaces, tasks, equipment and products based on characteristics of people's limitations and capabilities (Chengalur et al., 2004).

Handling. The term used to describe a condition of moving an object from one place to another whether by lifting, conveying, lulling, lowering or sliding. The term manual handling is used if the motion is performed utilizing a person's muscles (Chengalur et al., 2004).

National Institution for Occupational Safety and Health (NIOSH). Is a research institute within the Department of Health and Human Services in the United States that provides scientific data to OSHA (Chengalur et al., 2004).

The Occupational Safety and Health Administration (OSHA). A United States governmental agency charged with prevention of work related illnesses and injuries, saving lives while at work and promoting healthy work environments (Bridger, 2009).

Chapter II: Literature Review

The purpose of this study was to analyze the ergonomic-based risk factors associated with the utilization of the wig-wag machine at Company XYZ. The present use of the wig-wag machine at the company is associated with several risk factors such as repetitive motion, awkward posture, and excessive work exposure time. Such risk factors place the respective wig-wag machine operators at risk for developing various types of work-related musculoskeletal disorders. This literature review will cover several ergonomic areas related to this study including an introduction to ergonomics, basic terminology, common types of cumulative trauma disorders (CTDs), causes of such ailments, ergonomic worksite/job assessment and assessment tools, anthropometry, and ergonomic control measures.

Introduction to Ergonomics

It appears that the concept of ergonomic activities and adapting work to human capabilities and limitations is not a new practice. Examples can be found even in ancient times when humans utilized objects found in the environment such as wood and stone to satisfy their needs. Those tools were selected because of their proportionality to fit the human hand. Another example of the ancient practice of ergonomics appears in the designing of clothes and making of shelters (Kroemer, Kroemer & Kroemer-Elbert, 1994). Over time, as societies grew and became more complex and demanding, sophisticated systems were needed to manage growth challenges. During and after World War II, the growth of the profession of ergonomics was associated with the development of engineering psychology laboratories in the United States to meet the needs of the military as equipment and aircraft became more advanced. After the 1970s, the interest in ergonomics has grown to cover industrial and occupational aspects (Niebel & Freivalds, 1999). Furthermore, the scope has expanded to involve computer equipment, software, and office workstations. Another contributor to the expansion of ergonomics has been due to an increase in products and services liability, injury/illnesses cases, and catastrophic technology failures and disasters such as the nuclear incident at Three-Mile Island. The continuous growth of technology, workstations, and tools reflects the massive need for the development of ergonomics in order to design improved work environments, equipment, services, and products to promote the quality of life (Niebel & Freivalds, 1999).

Ergonomics is a multidisciplinary science that attempts to optimize the worker-environment relationship by taking into account human limitations and capabilities (Tayyari & Smith, 1997). To accomplish this goal, a basic understanding of other disciplines such as psychology, physiology, anthropometry, industrial system engineering, cognitive science, math, and physics is required. In the system design process, ergonomists perceive humans as the most important component of the system and all other man-made tools, products, services, machines, devices and workstations should obey the user's rule by adding to human capabilities and overcoming limitations. This user-oriented design philosophy not only takes advantage of human capabilities, but also builds a cohesive shield against undesirable consequences. A reasonable measure of the success of this philosophy can be observed through improved safety and health, efficiency and productivity (Kroemer et al., 1994).

In general, the two distinct categories which fall under the umbrella of ergonomics include studying human characteristics, limitations, and capabilities to be used in engineering designs and the act of utilizing the obtained data to design tasks, workstations, machines, or shelters to fit the user. This is accomplished through observations and assessments of the worker-environment interface and the actual practices of the worker to establish improvements. These assessments aim to identify risk factors such as repetitive tasks, awkward postures, extreme forces, and generate solutions before they contribute to the occurrence of musculoskeletal disorders (MSDs) and/or downgrade other organizational assets. This will ultimately lead to the "humanization" of work, which is the main objective of ergonomics (Kroemer et al., 1994).

Basic Terminology

The following ergonomics terminologies have been defined for the reader to provide a better understanding of work-related musculoskeletal disorders and related risk factors (Putz-Anderson, 1988):

- Posture: the position of the body or its parts during a work task.
- Adduction: movement toward the central axis of the body that reduces the angel between the limb and sagittal plane.
- Abduction: movement away from the central axis of the body that reduces the angle between the limb and sagittal plane.
- Flexion: movement of a joint whereby the angle between the two adjustment bones is diminished.
- Extension: movement of a joint whereby the angle between the two adjustment bones is increased.
- Pronation: the action of rotating the forearm in which the palm faces down, and back of the hand is positioned up.
- Supination: the action of rotating the forearm in which the palm faces up, and back of the hand is positioned down.
- Ulnar deviation: the action of bending the wrist toward the little finger.
- Radial deviation: the action of bending the wrist toward the thumb.
- Pinching: flexing the thumb against the index finger.

Cumulative Trauma Disorders (CTDs)

The relation between work and cumulative trauma disorders CTDs (also regarded as musculoskeletal disorders) dates back many years. More than 200 years ago, Bernardino Ramazinni, an Italian physician, discovered that "irregular work motion" (now one of the work-related risk factors) could contribute to adverse health effects (Putz-Anderson, 1988). The correlation between job/work risk factors and CTDs has gained considerable interest over the last decades. The reason behind this is that a number of health issues have increased as a consequence of the fast growth and massive demand of new production systems (Tayyari & Smith, 1997). However, CTDs have become more prevalent over the past years, like a poisoning epidemic throughout workplaces, due to the lack of awareness. These disorders are not only causing adverse health effects to mankind, but they are also placing an enormous burden on economic aspects of businesses as represented by the enormous cost associated with lost work time and labor turnover (Putz-Anderson, 1988).

When defining CTDs, it is beneficial to divide the term into three categories to enhance understanding. The first part, **cumulative**, means that injury/illness can develop gradually over time, and the time period could reach to years. The second part, **trauma**, designates an injury resulting from mechanical stress. The third part, which is **disorder**, refers to an anomalous condition. Since the first appearance of CTDs, several terms or labels have been used to describe these disorders. Examples of these terms include repetitive strain injury, repetitive motion injury, wear and tear disorders, osteoarthroses, and overuse injury (Putz-Anderson, 1988). However, the most common used term is CTDs, which refers to a group of musculoskeletal disorders that can cause injury to muscles, bones, nerves, tendons, joints, tendon sheaths, and ligaments in the upper extremities (e.g., shoulders, elbows, and hands) and lower extremities (i.e., knees and feet) (Putz-Anderson, 1988).

CTDs are not related to specific occupations or processes, nor are they a result of an incident or sudden injury. These types of disorders develop gradually over time as a consequence of inappropriate or excessive use of musculoskeletal components. In fact, CTDs can occur as a result of a combination of more than one ergonomic risk factor such as awkward posture and extreme force. Another dilemma of CTDs is that they are not visible and develop slowly over a prolonged period of time, so people cannot recognize such injuries or illnesses until chronic symptoms arise. However, pain, abnormal or limited joint movement and tissue swelling are considered to be the most reliable symptoms of CTDs (Putz-Anderson, 1988). When such symptoms appear, sufficient rest and an early symptoms report are effective ways of addressing the injury (Chengalur et al., 2004).

Common Types of Cumulative Trauma Disorders (CTDs)

Before discussing the common types of CTDs, it is important to differentiate between this group of disorders and strains and sprains. One of the main distinctions is that strain and sprain injuries can be caused by a single event or incident such as slipping or falling, while CTDs develop over a long period of time. Like strains and sprains, CTDs may involve symptoms such as swelling and pain, with the most common types of CTDs being the following (Putz-Anderson, 1988):

Tendinitis. Tendinitis, also known as tendonitis, is an inflammation of a tendon that occurs if the tendon is repeatedly tensed. Tendons are fibers that may fray or tear apart as a result of over exertion. Therefore, tendons should receive sufficient rest or recovery time otherwise they may be weakened or calcify (Putz-Anderson, 1988). In tendinitis, the inflammation can be caused from direct blows to the tendons or else trauma from a repeated use of the same member for a prolonged period of time. Symptoms of tendinitis involve swelling and dull ache over the affected area, pain and burning sensation, and restricted ability to use the affected joint (Tayyari & Smith, 1997). Bridger (2009) indicated that tendinitis can be caused in the workplace by single risk factors such as force, repetition or posture, and the risk is higher if these stressors are combined (Bridger, 2009).

Tenosynovitis. Tenosynovitis, also referred to as tendosynovitis, tendovaginitis, tenovaginitis and peritendinitis, is an inflammation of the synovial sheath which surrounds tendons, as a result of rapid and repetitive movement. As a result of the high repetitive movement of hand or fingers, the sheath produces excessive amounts of synovial fluid that accumulates under it, leading to pain and swelling. The disorder of tenosynovitis can occur if an activity involves repetitions exceeding 1500 to 2000 per hour (Putz-Anderson, 1988). In fact, factors such as aging, gender and specific systematic diseases all effect and contribute to tenosynovitis (Tayyari & Smith, 1997). Symptoms of tenosynovitis involve pain and swelling in the affected joint, redness along the tendon and tenderness around the effected joint, especially in the wrists, hands, ankles, and feet (Vorvick, 2012).

Ganglionic cyst. Ganglionic cyst is another tendon sheath disorder that appears as swollen nodules on the finger tendons at the wrist. As a result of accumulated synovial fluid under the sheath, a bump under the skin is created (Tayyari & Smith, 1997). These bumps may be firm or soft and have a rounded or oval shape and appear most of the time on location such as the top of the wrist, the palm side of the wrist, the top of the end joint of the finger, and the base of the finger on the palm side (Mayo clinic stores, 2006). Even though a ganglionic cyst is sometimes painless, the affected joint may still ache and be weak (Tayyari & Smith, 1997).

Epicondylitis. Epicondylitis is another form of tendinitis that involves tendon inflammation at the elbow area. There are two common types of epicondylitis that mainly result from strain or overuse of forearm muscles. These two types are lateral epicondylitis (tennis elbow) and medial epicondylitis (golfer's elbow) (Tayyari & Smith, 1997). If the lateral finger extensor muscles that are attached to the elbow are strained or overused, this will ultimately cause irritation of the tendons on the outer side of the elbow (lateral epicondylitis). On the other hand, if the strain or the overuse involves the finger flexor muscles, this will cause irritation of the tendons on the inner side of the elbow (medial epicondylitis) (Putz-Anderson, 1988). Symptoms of epicondylitis involve an ache at the elbow, swelling and weakness in the elbow area, or a burning sensation. In the workplace, tasks that are associated with repetitive forearm rotation in combination with wrist extension, such as using a screwdriver, place workers at risk of developing epicondylitis (Tayyari & Smith, 1997).

Carpal tunnel syndrome (CTS). CTS is one of the most common occupational-related musculoskeletal disorders that develops in the upper extremities. The carpel tunnel is a narrow opening in the wrist, in which median nerve and long tendons pass through (Bridger, 2009). Any interruption or increased pressure in the carpal tunnel has the potential to cause CTS. This usually happens when the finger flexor tendons that pass through the carpal tunnel become irritated or swollen and the median nerve becomes compressed (Putz-Anderson, 1988). This will cause impairment of sensory and motor function of the hand, along with pain, numbness, and tingling in the palm and fingers (Tayyari & Smith, 1997). Bridger (2009) mentioned that CTS is associated with jobs that require high force exertion, high repetitive motion, and extreme posture deviation, especially at the wrist. Because of the similarities in symptoms with several other CTDs, CTS may often be misdiagnosed (Tayyari & Smith, 1997).

Thoracic outlet syndrome. Thoracic outlet syndrome is one neurovascular disorder that affects both nerves and blood vessels. This type of disorder occurs when the nerves and blood vessels between the neck and shoulders are damaged as a result of compression. When workers frequently carry heavy objects or are subjected to excessive shoulder abduction, they are at risk of developing thoracic outlet syndrome (Putz-Anderson, 1988). Symptoms of this disorder involve numbness of the fingers and a weakened pulse at the wrist. Thoracic outlet syndrome can also be called neurovascular compression syndrome, cervicobrachail disorder, hyperabduction syndrome, brachial plexus neuritis, and costoclavicular syndrome, depending on the exact area that has been affected (Putz-Anderson, 1988).

Low back pain. Back injury is one of the most common and widespread work-related musculoskeletal disorders. The Bureau of Labor Statistics (BLS) indicated that back injuries constitute one out of every five workplace disorders and leave more than a million workers in pain each year. Moreover, one-fourth of the total worker compensation claims in the United States are related to back injury (cited in Department of Environmental Safety, 2005).

In order to understand back injury and its causes, it is necessary to understand the basic structure of the back and spine. The back is made of bones, muscles, intervertebral disks, tendons, ligaments, blood supply, nerves, and the spinal cord. The spinal column has a shape of a double-s that is made up of 33 vertebrae. In natural and balanced posture, the spine possesses three curvatures: cervical lordoses, thoracic kyphosis, and lumbar lordosis (Tayyari & Smith, 1997). The cervical lordoses curve consists of seven vertebrae that form the structural frame of the neck. Next is the thoracic kyphosis curve that is made up of 12 vertebrae. After the thoracic kyphosis are the five vertebrae of the lumbar lordosis. Then five sacral and four or five coccygeal vertebrae lie below the lumbar curve. These 33 vertebrae are connected together by ligaments and separated by intervertebral disks that provide flexibility to the spine during movement. While the spinal cord passes through the spine, a total of 31 pairs of nerves branch out through the vertebrae transferring signals between the back and the entire body (Tayyari & Smith, 1997).

Tayyari and Smith (1997) believed that back injuries, most of the time, develop over a long period of time as a result of wear and tear, and they are, in fact, rarely caused by a single incident. Back injury can be classified into three categories: acute, subacute and chronic (Bridger, 2009). Acute back pain is usually a result of muscle fatigue and usually lasts for a few weeks. Subacute may be generated from severe injury or injury to an injured body part and usually lasts for up to three months. The last and the most severe type is chronic pain, which may last for more than three months and cause distortion to one or more mechanical functions of the back (Bridger, 2009). Approximately 85% of lower back pain causes are uncertain. Back and lower back pain may not be caused directly by work-related activities, but ergonomic risk factors in the workplace can amplify the pain. Fortunately, these injuries can be prevented or delayed (Bridger, 2009).

Back pain problems vary and this is dependent on the affected part. In fact, the most fragile parts of the spine are the intervertebral disks, especially those in the lumbar curve and this explains why most back injuries occur in the lower region. The spinal disks become even weaker and less resilient with aging, which elevates the risk of developing such injury. However, back injuries may develop due to different problems, such as fatigue to muscles or tendons around the spine, nerve compression, muscle spasms, lumbar strain, compression fracture of vertebrae, unstable vertebrae and herniated intervertebral disks (Tayyari & Smith, 1997). Most of these problems can be induced by workplace activities that are associated with one or more of the following stressors (Tayyari & Smith, 1997):

- Overexertion in manual material handling such as lifting, pulling and lowering
- Lifting while the back is flexed or twisting the spine and horizontal reaching for distant objects
- Reaching above the shoulders, especially while lifting
- Awkward posture while sitting or standing, such as excessive inward flexion of the lumbar region

- Prolonged work durations, whether sitting or standing
- Vertical vibration generated by machines such as those used in construction

Causes of Cumulative Trauma Disorders

The occurrence of CTDs has been strongly associated with occupational and industrial actives that require carrying heavy objects, lifting, lowering, twisting of body trunk, raising shoulders, stooping, and bending the neck (Hossein, Reza, & Abolfazl, 2011). In fact, not only jobs that require high physical demand, such as automobile assembly, contribute to CTDs, but also less physically demanding jobs, such as computer data entry, possess high potential to cause such disorders (Tayyari & Smith, 1997). Moreover, musculoskeletal disorders can be caused by non-occupational factors, yet job-related risk factors can amplify the risk. The five main work-related risk factors which may contribute to the onset of CTDs or MSDs include awkward posture, repetitive motion, excessive temperature, excessive work exposure time, and extreme force.

Awkward posture. For a clearer understanding of awkward posture, the term neutral posture will first be defined. The term neutral posture is used to describe the condition where a muscle is at or near to its normal length and the joint is naturally aligned. Therefore, a posture is considered awkward if the movement of body parts is away from the neutral posture (Center for Disease Control and Prevention (CDC) & National Institute for Occupational Safety and Health (NIOSH), 2011).

Awkward postures are one of the leading ergonomic risk factors contributing to CTDs in the workplace. This factor has the potential to cause significant biomechanical stress on body components such as joints and soft tissue. Most joints and body parts have a wide range of movements, yet these components have certain limitations and capacities (Putz-Anderson, 1988). If these limitations are exceeded or if a joint is forced to move beyond its range, such components may tear apart or break and thus cause a CTD. Examples of awkward body postures include extreme flexion and extension of the wrist, ulnar and radial deviation of the wrist, spine flexion and extension, reaching behind or above the shoulder level, flexion and extension to the elbow, and forearm supination/pronation. Each of these awkward body positions could contribute to certain disorders. For instance, reaching behind or above the shoulder level has the potential to cause thoracic outlet syndrome (Putz-Anderson, 1988).

If a joint is forced to assume an extreme posture away from the neutral posture, tissues around the joint can be stretched or compressed based on the associated muscle movement. For example, if the wrist is extremely flexed or extended, pressure from swollen tendons within the carpal tunnel increases which ultimately compresses the median nerve that passes along this narrow region. Moreover, the posture of any muscle or its associated joint affects the muscle's maximum output. If a muscle is maintained in its neutral posture, this helps to produce force within its maximum capacity. On the other hand, if a muscle is not in the range of its neutral posture, this lowers its output, which could cause fatigue or injury. In other words, the risk of awkward posture can be elevated if combined with other risk factors (CDC & NIOSH, 2011).

Adverse health effects resulting from work-related activities that require standing or extended standing durations constitute significant concern. Tools, materials and controls to be used by standing workers should be positioned properly in order to avoid unacceptable movements, such as an unnatural hand posture, stooping and spine flexion, neck bending, excessive reaching in front of and behind the body, and twisting of the spine (Chengalur et al., 2004). In general, handled objects are best if such are placed between the worker's hip and shoulder height. Three main elements which should be considered when designing a work surface for standing operators include work surface height, horizontal distance between the worker and the work surface and the duration of time standing. Work surface height should be at or close to the standing elbow height. When carrying heavy objects, it is suggested to lower the work surface height to minimize fatigue and maximize worker exerted force (Bridger, 2009). Chengalur et al. (2004) reported that most people are able to reach about 18 inches in front of the arm without spine flexion as well as reasonably access an object which is placed within 43 to 65 inches off the floor and not more than 18 inches to the side of the body centerline. In addition, if stooped posture or extreme reaching is a must, such posture should not be maintained for a period longer than one minute (Chengalur et al., 2004). Activities that require excessive standing durations have the potential to cause localized-muscle fatigue, especially in the gastrocnemius muscle which is located in the back part of the lower leg. Further considerations can aid in minimizing fatigue and enhancing comfort while standing as follows (Bridger, 2009):

- **Toespace.** Absence of toespace forces the worker to stand away from the work surface, which can place more stress on the spine. Fatigue can develop as a result of flexing the lumbar and thoracic parts of the spine while standing, which can therefore be eliminated by providing toespace.
- **Shoes.** The type of the shoes worn when performing activities that require standing have the potential to cause fatigue to the lower legs and feet. During standing, high-heeled shoes can reduce efficiency of walking and increase postural load. In contrast, wearing flat shoes is associated with less muscle fatigue and discomfort.
- **Footrest and footrails.** Utilizing footrests or footrails contributes to reducing fatigue and discomfort to the lumbo-pelvic region. This may be because footrests or footrails have the ability to straighten legs, minimize pelvic tilt, and optimize the plantarflexion function to support the foot (Bridger, 2009).

- **Anti-fatigue mats.** Mats which are manufactured from plastic, rubber, or other resilient surfaces are useful tools to minimize discomfort and fatigue in the lower leg, feet, and back (Bridger, 2009). Moreover, they can improve postural stability by providing adequate friction between the workers' feet and the work surface.

Repetitive motion. Repetitiveness is the number of movements which are performed during a given period of time (Putz-Anderson, 1988), whereas the time interval needed to complete a sequence of events or elements is called cycle time (Chengalur et al., 2004). The human body is designed similar to a mechanical machine, which means if a worker continues to perform the same movement using the same body parts over a prolonged period of time, his/her body can wear out (Tayyari & Smith, 1997). It is believed that repetitive motion has a significant effect on the development of CTDs in the workplace. BLS indicated that repetitive motion contributed to the largest number of workplace absences in the year 2002, with the median days away from work being 23 (BLS, 2004). In fact, jobs that require high frequencies of repetition will eventually lead to trauma, even if the performed force is minimal. Muscles that are involved in highly repetitive motions or tasks need more time to recover than muscles which are involved in less repetitive tasks. In this regard, the likelihood of acquiring CTDs can be elevated if tensed or fatigued muscles have not received sufficient rest (Putz-Anderson, 1988). For example, in a frequent lifting task, fatigue of the shoulders, arms, hands, legs and back could accumulate if the break or rest time between lifts is insufficient (Chengalur et al., 2004). Moreover, if repetitive motion is associated with other risk factors, such as awkward posture or excessive force, the risk of such disorders can be elevated (Tayyari & Smith, 1997).

The cycle time of a task can be measured via direct observation, if possible, or by utilizing an assessment tool such as videotaping. A task is considered as a highly repetitive if it has a cycle time of less than 30 seconds. If the cycle time is more than 30 seconds, then the job is classified as being minimally repetitive. Examples of disorders that could result from repetitive motion are carpal tunnel syndrome and tenosynovitis (Putz-Anderson, 1988).

Excessive temperature. Besides the previously mentioned risk factors, thermal conditions in the workplace are also a main contributor of WMSDs. Moreover, thermal changes possess the potential to downgrade worker productivity and efficiency and create accidents such as explosions and fires (Tayyari & Smith, 1997). The term thermal stress refers to the balance between metabolic heat production and the rate of heat loss, and if this equilibrium is achieved, this is then referred to as thermoregulation. The ideal human core temperature falls in the range of 36°C-37°C. While a core temperature of 33°C leads to the onset of cardiac disturbances, rises in temperature to over 42°C or drops to lower than 25°C are considered fatal, with 35.5°C being the lowest acceptable limit (Bridger, 2009). At the workplace, the human core temperature or the concept of thermoregulation can be disturbed by two main risk factors, heat stress and cold stress (Chengalur et al., 2004).

Heat stress can be defined as the total physiological load of all internal heat factors, such as body temperature, metabolic heat, and degree of acclimatization, and the external heat factors, such as humidity, clothing, wind velocity, and radiant heat (Tayyari & Smith, 1997). Heat can place tremendous stress on the cardiopulmonary system and thus contribute to heat-related disorders. Moreover, this risk factor can reduce the organizations' production, quality and performance by elevating the likelihood of accidents. Heat stress can be induced by the nature of the work environment (hot or warm weather), high work demand, or tasks associated with processing heat (Chengalur et al., 2004). Tayyari and Smith (1997) stated that heat-related disorders or illnesses may occur if a person's body fails to tolerate hot conditions. Examples of these disorders include heat stroke, heat exhaustion, heat cramps, and prickly heat. Some approaches that can reduce the effects of heat stress involve air conditioning or refrigeration systems, microclimate (personal) cooling systems, adequate ventilation systems, ample intake of cold beverages and isolating workers from heat sources (Tayyari & Smith, 1997). In fact, the body's capability to tolerate hot temperatures can also be influenced by personal factors such as age, sex, physical fitness, and body fat. Heat stress has a tremendous impact on human health and wellness; however, negative effects can be prevented by either minimizing the metabolic heat production rate or protecting the worker from the heat source as much as possible. Heat stress is present in many workplaces, and unfortunately this risk factor is often underappreciated (Bridger, 2009).

Another temperature-related risk factor that can create adverse health effects is cold stress. Cold stress or cold discomfort is dependent on environmental conditions, such as air temperature, wind, metabolic rate, and amount of clothing that controls skin cooling and loss of body heat (Chengalur et al., 2004). Tayyari and Smith (1997) believed that the issue of cold stress is not as significant as heat stress. However, cold stress could cause loss of cognition and psychomotor skills. Moreover, exposure to extreme cold stress has the potential to cause adverse health effects such as a low body temperature, weakness of the muscles, numbness, shivering and drowsiness. Like heat stress, cold stress can reduce a worker's output and efficiency because most of his/her time and energy is utilized for self-preservation (Tayyari & Smith, 1997). Cold stress is found in situations such as outdoor work in cold climates, unconditioned spaces during winter, as well as refrigerated areas (Chengalur et al., 2004). It is suggested that cold stress can be decreased by increasing the daily food intake, especially warm beverages. This will ultimately increase the body's metabolic rate and the thickness of the subcutaneous fat layer, which contributes to a higher rate of heat production and isolation of the core temperature. Moreover, to promote the mitigation of cold stress, the head should be protected in a similar manner as the hands, feet, and other extremities. This is due to the fact that approximately 25%

of the overall body heat loss occurs if the head is cold (Bridger, 2009). Even though cold stress is not as critical as heat stress, serious consideration should be taken to eliminate or minimize its adverse health effects (Tayyari & Smith, 1997).

Excessive work exposure time. Many businesses such as factories operate beyond eight hours per day to meet a certain level of demand and increase their production rate. However, increasing working hours, especially beyond ten hours, does not always increase productivity as expected, and, in some cases, total output may decline as a result of a decrease in the work pace. On the other hand, shortening working hours may contribute to an increase in employee output and total production (Grandjean, 1988). Regardless of the negative effect of lowered productivity, excessive exposure time beyond eight hours may also lead to undesirable consequences such as adverse health effects and sickness, absenteeism, and increased risk of accidents (Grandjean, 1988).

The use of periodic rest pauses can be one approach that aids in avoiding the negative work stress-related outcomes which were previously mentioned. In fact, time spent on rest pauses is not wasted but rather can speed up the work and thus increase productivity rather than decrease it. Employee output during busy hours at work tends to decrease towards the end of the shift. In general, rest pauses should amount to 15% of the total working time, and may reach 20% to 30% of the total time in heavy-duty jobs. Rest pauses of three to four minutes each hour help to recover from fatigue and boost concentration, and thus reduce employees' errors. Also, rest pauses can provide ten to fifteen minutes of relief during the morning and afternoon to allow for refreshment and reduce body fatigue (Grandjean, 1988). Activities that are within the optimal capacities of high potential workforce may become risky if sustain for 30 to 45 minutes. To prevent the occurrence of fatigue, heavy work activities should not be sustained for more than 15 minutes, and such tasks may become risky if they are maintained for greater than this period of time without providing the employee with breaks (Chengalur et al., 2004). Therefore, rest pauses should be arranged in a manner so that the total energy expended per working day does not exceed 20,000 kilojoules (kJ). Rest pauses between tasks should be introduced in order to maintain balance between the body energy and consumption (Grandjean, 1988).

Many corporations or organizations differ with regard to the nature of the business, work requirements, number of workers, type of product, and other factors. For economic purposes, most of the manufacturing processes in these organizations need continuous production. These two notions are the main reasons for introducing the concept of shift-work systems (Tayyari & Smith, 1997). There are, in fact, numerous types of work-shifts or work schedules today, such as early shift (0600-1400 hours), late day-shift (1400-2200 hours), night-shift (2200-0600 hours) and the 8-16-24 hour shifts. However, from a health and ergonomics standpoint, a 12-hour working day, including over-time, is not recommended (Grandjean, 1988). Working shifts and over-time may place workers at risk of adverse health effects, muscle fatigue and soreness, elevated risk of accidents, and lowered productivity. The scope of fatigue-based issues which result from excessive working hours may be expanded to include lack of sleep, energy, motivation and satisfaction, and thus increase the likelihood of making mistakes. Due to these negative effects, worker performance tends to decline by the end of the shift, which leads to an increase in the level of risk of accidents (Bridger, 2009). Even though there may be some benefits associated with the 12-hour shift system, such as increasing the worker’s salary, the negative effects may be predominant in most cases. Therefore, if an individual is required to work for prolonged durations, the design or redesign of such shifts should consider the variety of adverse health affects and develop appropriate solutions (Bridger, 2009).

Extreme force. Force, which is necessary to perform occupational tasks such as pulling, pushing, and lifting, can lead to the development of a CTD injury or illness. The load that is placed on the body can easily cause wear and tear on its soft tissues, such as muscles, tendons, and ligaments, especially if the pressure or load is too great (Putz-Anderson, 1988). In general, the two types of work include dynamic work and static effort. Dynamic work refers to tasks that involve obvious movement of the whole body or any of its parts. This body movement usually attempts to accomplish external work against a resisting force, usually over a distance, and this is distinct from static work. However, the required physical demand of dynamic work contributes to energy expenditure. As energy expenditure increases, physiological adjustment increases in order to supply the oxygen that is required to support the metabolic demands and remove carbon dioxide (Chengalur et al., 2004). If the adjustment is insufficient, lactic acid may build up in the body as whole, which may result in whole-body fatigue. This will accelerate exhaustion and lower psychomotor skills. The rate of oxygen consumption can be used as a measure of the dynamic work demand (one liter of oxygen equals five Lcal of energy expenditure). It should be noted that as oxygen consumption demand rises, endurance time decreases. In dynamic work activities, recovery time should be allowed in order to avoid exhaustion and whole-body fatigue and thus avoid CTDs injuries. In general, the total demand should not exceed 33% of the maximum aerobic limit during an eight-hour shift, 30 % for ten-hour shift and 25% for twelve-hour shift (Chengalur et al., 2004). The required force limit for a design should always consider the workers' limitations, which are dependent on a number of variables such as gender, age, and body strength (Putz-Anderson, 1988).

Static work, in contrast, can be defined as any task that involves little or no movement of the body or any of its parts which require sustained muscle contraction. It is believed that static work has the potential to cause adverse health effects including local muscle fatigue. If a static work is maintained for an extended period of time, blood flow to the utilized muscles group may be restricted, which eventually reduces the amount of oxygen provided to these muscles. Thus, due to the lack of oxygen, muscle energy declines and anaerobic muscle metabolism issues may become present (Chengalur et al., 2004). Moreover, contraction time is one factor that could accelerate muscle fatigue. As muscles are under sustained contraction and statically loaded, more lactic acid builds up, which then contributes to an increase in the sensation of discomfort and exhaustion. Logically, as the contraction time increases, more recovery time is needed to bring the muscle back to the resting state, which is dependent on the amount of the accumulated lactic acid. However, the risk of static work is elevated gradually if it is associated with another risk factor such as awkward posture (Chengalur et al., 2004). This is because each group of muscles has specific postures that allow optimal forces to be exerted. However, regardless of whether the expended effort is light or heavy, postural fatigue of the supporting muscles is possible. Even though the amount of time a worker is willing to spend in static work may vary depending on body strength and fitness, local muscle fatigue has a great potential to occur, especially if the activity is associated with other risk factors such as excessive exposure time, awkward posture, and insufficient resting time (Chengalur et al., 2004).

The risk level of occupational risk factors and the potential for the development of CTDs increases with aging workers. Thus, when designing a task, it is essential to account for an aging workforce as a mitigating factor. With age, various physical and mental human capabilities decline, such as maximum muscle strength, aerobic capacity, hearing, heat tolerance, sense of balance, and even the ability to recover from previous injury or illness (Bridger, 2009). Tayyari and Smith (1997) mentioned that a muscle reaches its optimal strength at the age of 20. According to Bridger (2009), maximum grip strength becomes poorer with age, and declines by 20% between the ages of 20 to 60, and by about the half by the age of 75 and above. Moreover, with the aging process, the human body’s heat tolerance declines and the pulmonary and cardiovascular systems do not function as well as during an individual’s younger years. Thus, working in hot environments stresses the thermo-regulatory system even more and may also introduce mental stressors (Tayyari & Smith, 1997). In the workplace, the vast majority of tasks rely on sight and the ability to detect and observe the periphery, which becomes more difficult with old age. Human vision deteriorates with age as the visual functions of the eyes degenerate. With age, the human near focal point moves further from the eye, resulting in the loss of the ability to focus sharply on close objects (Chengalur et al., 2004). For an aging workforce, the likelihood of developing WMSDs among individuals over 40 years is higher, thus, it is essential to consider the previously mentioned limitations when designing or redesigning the workplace, tools, or equipment (Tayyari & Smith, 1997).

Ergonomic Worksite/Job Assessment

One of the main activities which are associated with ergonomics is the observation of the work environment and its interaction with the users. Observations should always be conducted in order to design human-work interface, design new tools/equipment, establish training programs, and maximize human practices. In fact, this can be accomplished through a worksite/task analysis that can be used during both the design of a new system and evaluation of an existing system design (Putz-Anderson, 1998).

A comprehensive worksite or job survey is a powerful approach to gain an understanding of the deficiencies associated with the worksite and its activities. It can be conducted to determine existing or potential work-related risk factors such as force, repetition, posture, temperature and duration of exposure, in addition to the identification of the root causes of such risk factors (Tayyari & Smith, 1997). Worksite/job analysis usually involves a series of systematic actions as follows (Department of Licensing and Regulatory Affairs (LARA), 2012):

- Hazard identification
- Comprehensive hazard surveys

- Hazard analysis of changes in the workplace
- Routine hazard or job analysis
- Periodic workplace safety and health inspections
- Worker reports of hazards
- Accident and near miss investigations
- Injury/illness trend analysis

The baseline of this effective technique is the comprehensive hazard survey of existing and potential hazards. After a baseline has been attained, periodic surveys and inspections need to be conducted in order to gather information about the previously observed hazards and recognize new hazards that may be introduced to the system after changes. In fact, there will always be changes to the facility, tools, processes, material, or even people, so periodic inspections are an essential element because they help to recognize new hazards before a loss is likely to occur (Department of Licensing and Regulatory Affairs (LARA), 2012):

In general, the goal of an ergonomic assessment is to recognize and identify areas where errors are present and then establish the necessary corrections. This will ultimately boost the productivity and overall performance through improving workers' safety and health (Tayyari & Smith, 1997). In fact, ergonomic worksite assessment should use systematic procedures and be conducted by a trained and experienced person who is familiar with the process. It is important that these analysts have access to historical data such as OSHA and worker compensation records to improve the quality of the results, though employees who work in areas of concern can also assist in the process of performing an ergonomic assessment. They are usually more familiar with the process and can provide valuable information and more details about the suspected hazards. The gathered data from observations are then used to develop appropriate and feasible control methods to reduce or eliminate the risk, whether through redesigning the task, redesigning workstation, modifying equipment, or personal training (Chengalur et al., 2004).

There are a variety of validated ergonomic worksite assessment tools that focus on the identification of ergonomic risk factors such as awkward posture, force repetition temperature, and other environmental stressors. These tools vary from basic and simple checklists to detailed quantifications of each risk factor. The use of such tools is dependent on the complexity of the task, the amount of needed information, and the level of training required to use the assessment technique (Monroe, 2006). Examples of common and effective ergonomic assessment tools that may be utilized in worksites/jobs investigations include the Rapid Entire Body Assessment (REBA), Ergonomic Task Analysis Worksheet, employee symptom survey, and a review of available regulatory injury/illnesses records.

Rapid Entire Body Assessment (REBA). The Rapid Entire Body Assessment (REBA) is a powerful ergonomic risk assessment tool that was developed to assess work-related postures and risk of MSD. This method was initially developed by D. Sue Hignett and D. Lynn McAtamney to be used in healthcare and other industrial services, yet it can be applied to various tasks that involve whole body movement, static and dynamic postures, and load movement. The primary risk which REBA assesses is posture and the final score increases as the body parts move further away from the neutral posture. This method takes into account other risk factors such as force, repetition, and duration. The REBA assesses both upper and lower extremities including forearms, wrists, shoulders, elbows, necks, trunks, backs, legs, and knees. Basically, six steps are required to complete the assessment (see Appendix A) and include observing the task, selecting the posture to be assessed, scoring the posture, processing the score, locating the REBA score, and confirming the action level needed to control the risk (Hignett & McAtamney, 2000).

Prior observation of the task being analyzed in order to identify the assessed posture is important to perform a REBA assessment. Selecting the appropriate posture for assessment may be based on the most frequently used, longest maintained, or most extreme postures. The posture classification system on the REBA worksheet is dived into two groups which are A and B. Group A includes neck, trunk and legs, while group B includes upper arm, lower arm and wrist. For group A, the score of each body segment is calculated individually with regard to the joints angles or range of motion. The final score of group A includes the sum of neck, trunk and leg scores in addition to the force/load score. The same process is repeated to calculate the final score of group B with regard to the coupling and activity scores instead of the force/load scores. The final scores of groups A and B are transferred to table C to calculate the final REBA score which indicates the level of risk exposure and guides the management to implement further investigation/corrective actions. The REBA assessment's scale of corrective actions includes five levels that assist in controlling the assessed risk factors. In general, as the final REBA score raises, the risk level and the urgency for the need to make changes or interventions increases (Hignett & McAtamney, 2000).

The REBA assessment can be applied in both the pre- and post-design stages, and then the risk level (Score) of both phases can be compared. This method can provide meaningful results in a timely manner. The developers of this method suggested that tools such as photographs or video recordings can be helpful in observations in order to promote the quality of measurements. Unfortunately, REBA does not have a combined score for the left and right sides of the assessed body, thus, the method should be applied on both sides. Furthermore, this method does not consider factors such as gender, age, or medical history (Hignett & McAtamney, 2000). Following are various forms of ergonomic instrumentation that can be utilized to assist in the REBA assessment process:

- **Videotaping.** Analyzing the task through videotaping is a traditional and useful method that enhances the quality of accuracy of the assessment. The operator's movements can be recorded while he/she is performing the job of concern to pinpoint any the associated deficiencies. It is suggested that the longer the task is recorded, the more accurate the results, and 2-3 cycles is the lowest suggested number. Then, the video recording is played several times at different paces to assist in identifying various risk factors such as awkward posture and repetition. Each time, the observer concentrates on a certain body part or movement and documents the unacceptable postures or frequency in each cycle or minute. For instance, the first time, the observer focuses on the neck and documents all the awkward postures. The next time, he/she concentrates on the back, and so on. Based on this, the risk level can be identified, and obtained values can be compared to published standards or regulations to ensure compliance (Fernandez & Marley, 2009).
- **Manual Goniometer.** A manual goniometer is one of the simplest and most effective forms of ergonomic instrumentation that is used to measure joints angles or range of motion. A manual goniometer can be utilized in conjunction with video recording or photos of the task being analyzed to measure joint angles, in degrees, between two adjacent body segments. Identifying joint angles associated with a task serves to provide more specific recommendations to control the present risk or comparing the task before and after interventions are implemented. A traditional goniometer is comprised of two extended arms in which the stationary arm is aligned with the central axis of one body segment, while the other arm is placed on the central axis of the adjacent limb. The degree between the endpoints is thus indicates the entire range of motion associated with the analyzed task (Workers' Compensation Board of B.C, n.d.).

Ergonomic task analysis worksheet. An ergonomic task analysis worksheet, developed by Great American Insurance Group, provides the user with methods to identify and evaluate each ergonomic risk factor. This task analysis worksheet identifies a variety of ergonomic risk factors including repetition, posture, vibration, reaching/proper height, force, static load, and other environmental risk factors such as noise, lighting, temperature, work pace, and floor surface (see Appendix B). Based on the severity of the observed risk factor and in reference to the drawing provided in the sheet, each risk factor will be evaluated and scored within three levels: ideal (1, 2, 3…30), warning level (1A, 2A, 3A….30A) or take action (1B, 2B, 3B…30B). While the ideal level means that there is no risk factor associated with the performed task, both the warning level and take action level indicate that a risk factor is present. The distinction between warning and take action levels is that the latter possesses the highest risk level where immediate action is required to eliminate the identified ergonomic risks.

Employee symptom survey. The employee symptom survey is a widely used method which assists in the identification of areas where ergonomic risk factors and potential or actual CTD problems are present. The collected data help to identify the number of employees who experience discomfort and then determine areas where potential risk factors exist. The number of reported cases indicates which areas need to receive the highest priority and control. The worker's positive response usually pinpoints that he/she is experiencing discomfort, yet it is difficult to diagnose a specific disorder due to the similarity in symptoms, so further diagnoses and exams are needed (Putz-Anderson, 1988). When designing the survey sheet, it is important to take into account several aspects such as length of the survey sheet, reading level of respondents, and time and method of administration. A CTD symptom survey developed by University of Wisconsin-Madison is presented in Appendix C. This survey provides several questions about the nature and location of the experienced pain in addition to other details such as employee medical history for related disorders and can be completed in a timely manner. The survey sheet includes a body parts map where the employees mark the body parts where they are experiencing pain or discomfort. This simple method requires minimum time and effort, but can uncover situations where discomfort and trauma disorders exist or have the potential to develop (Putz-Anderson, 1988).

Review of available records. Reviewing previous records can be considered the first step of a worksite analysis and may help evaluate the scope of risk factors and disorders which are present. Records such as the OSHA 300 log, injury/illness or worker compensation costs may provide meaningful information about trends of work-related disorders, accidents, and injuries (Putz-Anderson, 1988). The Occupational Safety and Health Administration (OSHA) recordkeeping requirements have been in place since 1971 and are designed to promote employers recognition and correction of hazardous conditions by tracking work-related illnesses and injuries and their root cause. OSHA 300 log is a form where most employers are required to record work-related injuries/illnesses, fatalities, days away from work, restricted work or transfer to another job, loss of consciousness, diagnosis of a significant illness/injury, or medical treatment beyond first-aid. The OSHA 300 log must be maintained at least three years following the year it relates. Access to such records must be provided to workers or authorized persons such as government representatives. However, employees' name and identifying information must be removed if the record needs to be shared with unauthorized individuals. Anticipated benefits of utilizing OSHA 300 log include promoting the identification of injury/illness and prevention efforts, facilitating safety and health inspections, providing statistical date to guide interventions prioritizing, enhancing employee and employer awareness about work-related disorders and their causes (Roughton, 1997). Worker compensation records can be used in estimating costs associated with work-related injuries and illnesses such as MSDs. Such costs can be classified into two areas which are medical (payment for diagnosis and treatment of MSDs) and disability (payment to the injured worker) costs. Worker compensation records may be useful tool to identify job-related injuries titles that cause high losses, but it may fail to reveal problems in early stages. Obtained information from records may also be used to compare activities or jobs between departments as well as within the same department, after which attention can be directed to existing and potential areas of risk. These records also can assist in evaluating the task after implementing control to ensure the efficiency needed (Putz-Anderson, 1988).

Anthropometry

Anthropometry is the study of the human body's physical dimensions and characteristics such as size of girth, breadth and distance between anatomical points, body segments mass (such as range of joint motion), center of gravity, and strength of muscle groups (Chengalur et al., 2004). The term anthropometry has been derived from two Greek words – *anthropos* (meaning man) *and metron* (meaning measure). Anthropometry is one of the core elements of ergonomics in which human-based data is be used to assist workplace designers to accommodate a wide range of the population into the design. The term population is used to describe groups of people who share occupations, a job's geographical location and ancestors (Bridger, 2009). A large amount of anthropometric data, tables, and figures have been published and categorized based on different percentiles of populations such as 5^{th}, 10^{th}, 50^{th}, 90^{th} and 95^{th} percentiles. For example, Anthropometric table of U.S anthropometric data, inches (Champney 1979; Muller-Borer 1981; NASA 1978) (Chengalur et al., 2004) (see Appendix D) represent data which are primarily acquired from military studies where several thousand of people were studied. The data between parentheses are obtained from industrial studies where 100-150 men and 50-100 were studied, while the data in the footnote are from an industrial study of 100 women and 50 men (Chengalur et al., 2004). Understanding the population is the key element when developing such data. The designer does not want to utilize human measurements that may not represent the population concerned since data which is used to design locker rooms for elementary school students would most likely not be applicable to professional basketball players (Tayyari & Smith, 1997).

In general, the three basic anthropometric-based design philosophies utilized by the designers include designing for the average, for the extreme and the range. The first approach, designing for the average, is used when designing facilities that would be utilized by a large number of people, such as public facilities and bus seats. This method is not preferred when one size cannot accommodate an entire population. Designing for the extreme approach is usually costly and not feasible. For instance, designing a car seat to accommodate the smallest person means it may not be comfortable or may not fit the largest person. The last and most common approach is designing for a range of a given population. A typical range is between 5^{th} to 95^{th} percentile and usually accommodates 90% of the population. In fact, the range of the population may vary depending on the cost and task criticality (Tayyari & Smith, 1997).

From the anthropometric standpoint, it is believed that the human-based data for a healthy population follows a normal distribution. The two parameters of the normal distribution include the mean (expectation) and the standard deviation (variance). The mean can be calculated by taking the sum of all individual measurements and dividing it by the number of the measurements. The difference between each individual measurement and the mean is used to calculate the standard deviation. While the value of the mean determines the position of the normal distribution, the standard deviation value indicates the shape of the distribution. The normal distribution is symmetrical, which means 50% of the obtained scores lie on either side of the mean (Bridger, 2009). Usually, the lowest and the highest values of the standard deviation determine how close the measurement is to the mean in which the smaller value is closer to the mean. However, the first step in determining these two parameters is to measure random samples of the respective population. Then, the equations (a) and (b) below are used to calculate the two parameters. The calculated parameters that are based on samples which are obtained from a certain population are called sample statistics (Bricger, 2009).

(a) $\bar{x} = \frac{\sum_{i=1}^{n} xi}{n}$ (b) $S = \sqrt{\frac{\sum_{i=1}^{n} (xi - \bar{x})^2}{n-1}}$

Equation (a) used to calculate the mean, and equation (b) is used to calculate standard deviation for a certain population, where x is the individual measurement and n is the number of measurements. The mean is calculated by dividing the sum of measurements by their number, while the standard deviation is the square root of the mean squared difference between each score and the mean (Bridger, 2009).

The two major types of anthropometric data utilized in ergonomics include structural and functional measurements. Structural or static measurements are those measurements of body segments at static postures (stationary). Examples include length of upper arm, sitting height, and hip breadth. In this regard, it is essential to consider the clearance dimensions, which determine the minimum allowable space needed to accommodate the largest population at the workplace, such as the size of doorways. Functional or dynamic measurements are those measurements of body segments which occur during musculoskeletal-based movement. Examples include reach envelops, range of joints movement, and kneeling height. In this regard, reach dimensions are taken into account to determine the maximum allowable reaching distance needed to accommodate the smallest population at the workplace, such as height of controls and door latches (Tayyari & Smith, 1997). In various workplaces, employees are required to wear heavy clothes or personal protective equipment. Thus, a designer should be cautious about allowance space in addition to the previously indicated dimensions (usually one inch is added for shoes). Note that finding the appropriate dimensions, whether static or dynamic, is a key element in deriving changes and recommendations for the workplaces, equipment, or tools (Tayyari & Smith, 1997).

The most significant part in anthropometry is how to use anthropometric-data. When designing for a certain population, percentiles are used to determine the proportion of the accommodated population, assess size limitations, and determine reasonable cut-off points (Tayyari & Smith, 1997). In general, a workplace, tool or equipment designed for a certain population is usually based on two assumptions which are minimum and maximum dimensions (Bridger, 2009):

- Minimum dimensions: A high percentile value such as 95^{th} and 99^{th} is chosen to represent the minimum allowable dimensions (clearance) needed to accommodate the largest population. For example, a doorframe should have sufficient head room to fit very tall people, and this can be accomplished by using a high percentile value that indicates the minimum height. Additional allowance spaces should also be provided in case of clothing such as a head helmet or high-heeled shoes.
- Maximum dimensions: A low percentile value is chosen to determine the maximum allowable dimensions (reach) which are needed to accommodate the smallest population. For example, a door latch should be located at an appropriate height so that the maximum vertical grip of the smallest person is not exceeded.

Tayyari and Smith (1997) provide a brief and clear procedure to use the anthropometric data to attain an optimal fit between the worker and the work environment:

- Define the workplace, equipment or product's user population such as a US civilian or worldwide population.
- Determine the proportion of the population to be accommodated by the design, such as 95%.
- Identify the body dimensions needed for the design, such as sitting height.
- Determine the accommodation type, reach, or clearance situation.
- Determine the percentile value of the dimensions of the defined proportion of population.
- Consider the type of clothing or personal protective equipment to identify the needed allowance.

Designers must always be vigilant when using anthropometric data as misuse can contribute to enormous and undesirable consequences. The designer, however, should be able to predict the severity of consequences and the affected people of any mismatch. The outcome of the inability of children to reach a handle of exit door, for instance, during emergency or fire situations demonstrates the seriousness of the mismatch. Usually, in each design there will be cut-off points. Determining the appropriate cut-off point is dependent on two factors which include the cost of design for a specific range of population and the consequences of an anthropometric mismatch. However, other aspects such as usability should not be neglected when determining the required dimensions (Bridger, 2009).

Ergonomic Control Measures

Controls are those interventions of using electronic devices or changing the operation system/process to control exposure to risk factors (Chengalur et al., 2004). As indicated in the previous section, data obtained from job analysis aid in identifying the source of CTDs or risk factors. Once the source is defined, a plan to prevent or control the present risk is established.

The selection of control techniques is dependent on the level of needed protection and the available financial-based resources (Putz-Anderson, 1988). In general, the three main approaches used to minimize the presence of harmful ergonomic risk factors include engineering and administrative controls, as well as personal protective equipment (Chengalur et al., 2004). This hierarchy of controls is designed to provide effective approaches based on the most protective and effective to the least (CDC, 2010).

Engineering controls are usually the most feasible and preferred approach and can be defined as any physical change in the current job, material, equipment, or product in order to eliminate or reduce the exposure to risk factors (Chengalur et al., 2004). These forms of controls are not dependent on operator self-protection, yet they are implemented to the source of the hazard to control the worker exposure to risk in the first place (Bridger, 2009). The initial implementation costs associated with engineering controls may be higher than those of administrative costs. However, the operating costs over the long-term for engineering controls are typically lower and thus may provide monetary savings in other areas (CDC, 2010). Examples of engineering controls involve the following (Tayyari & Smith, 1997):

- Job redesign: Investigations can help to identify which areas within a job which needs to be modified. Certain activities may not be necessary and others can be designed to be easier. Adjustments can be applied to accommodate the workers' limitations and abilities.
- Workplace redesign: In certain situations, the poor workstation design is the problem. Simple modifications of the workstation sometimes contribute to significant benefits. The modification or the redesign should consider the users' characteristics and limitations.

- Tool/equipment redesign: Tools utilized in the workplace may place unnecessary stress on the users. If tools are designed to match workers' characteristics, stressors can be eliminated. One way to accomplish this goal is by providing adjustable tools and equipment if multiple users utilize the same workstations.

In certain circumstances, applying engineering controls may be costly or may not be available. Thus, implementing administrative controls can be a preferred choice to provide valuable improvements (Tayyari & Smith, 1997). Administrative controls are methods to change the way the work is performed in order to reduce or eliminate the exposure to risk factors. These decisions or changes are usually established by the respective management/supervisory individuals (Bridger, 2009). The initial cost of implementing administrative controls may be low, but they may be costly in the long term. Administrative approaches are usually less effective and reliable than engineering controls as they place great strain on the workers (CDC, 2010). Examples of administrative controls are (Tayyari & Smith, 1997):

- Revision of work-rest schedule: If the work schedule has been observed to be exhausting or inappropriate, it can be modified to provide sufficient resting breaks that assist to recover muscles utilized during the activities of concern.
- Training: Even though effective measures are in place, the elimination or mitigation of risk factors and their effects cannot be achieved if the workers are not aware of the risk and how to avoid it. Workers should know what CTDs are and how to prevent them and be trained in the proper use of tools/equipment, neutral body postures, and other matters.
- Rotating workers among jobs: This solution attempts to rotate employees who are exposed to stressors between tasks that do not require the same motions or use of body parts. Therefore, muscles and other body parts can rest and heal while performing the other job.

- Exercise/rest provision: As indicated before, resting and breaks can mitigate body tension and relieve stress. Exercise programs can promote this goal and enhance workers' health.
- Job/career change: Solving the problem associated with the job is preferred to changing the employees' career, yet this approach is suggested if the engineering and administrative solutions are exhausted and could not solve the issues.

Personal protective equipment (PPE) is the least reliable approach of ergonomic control measures. Such approaches do not eliminate hazards, but they simply reduce the hazardous exposure by placing a barrier between the operator and the source of the risk. Unlike medical devices that are used after trauma, PPE is a preventive measure. Examples of PPE include vibration-observing gloves, finger guards, thumb and fireguard thimbles, kneepads, and hand pads (Tayyari & Smith, 1997).

Summary

This chapter provided an overview of ergonomics, which is the multidisciplinary science that attempts to optimize the relationship between a system and its users. From the ergonomics perspective, this goal is attainable if the human being is considered as an integrated aspect of the design process to produce goods and services, rather than as a secondary consideration. This approach assists in the elimination and reduction of unnecessary physical stressors placed by the work on its users. One application of ergonomics is engineering anthropometry which is the study of the human body's physical dimensions and characteristics such as size of girth and breadth. In general, the three basic anthropometric-based design philosophies utilized by the designers include designing for the average, for the extreme and the range. The two major types of anthropometric data utilized in ergonomics include structural (stationary) and functional (dynamic) measurements. Anthropometric data assist workplace designers to accommodate a wide range of population into the design and thus promote the relationship between the user and work environment which is a primary goal of healthy ergonomic practices. Further, ergonomic risk assessments can be conducted on in the early stages of a design or on existing systems, workplaces, jobs, tools, or products to identify potential or actual risk factors before they contribute to undesirable consequences such as employee discomfort, the development of CTDs, and lowering productivity. The five main work-related risk factors include awkward posture, repetitive motion, excessive temperature, excessive work exposure time, and extreme force. Combined or alone, these risk factors are the main contributors to ergonomic injury or acute/chronic CTDs. Ergonomic risk assessment tools such as the REBA, the ergonomic task analysis worksheet, the employee symptom survey, and a review of injury/illness records can aid in the identification of ergonomic risk factors. To promote the accuracy of assessment-based data, ergonomic instrumentations such as video recording and the use of a manual goniometer can be utilized. Based on the data obtained in the ergonomic assessment, ergonomists can identify the most protective and feasible control to implement in order to eliminate or reduce the risk to an acceptable level. In general, there are three types of control: engineering control, administrative control, and personal protective equipment. The selection of such controls is dependent on the level of protection and the available resources.

Chapter III Methodology

The purpose of this study was to analyze the ergonomic-based risk factors which are present for workers using the wig-wag machine at the Company XYZ and to assess the factors' contributions to work-related musculoskeletal disorders (MSDs). Ergonomic risk assessment tools such as REBA and the ergonomic task analysis worksheet were utilized to assist in the identification of the present and potential ergonomic risk factors associated with the current process. The evaluation of this study included an employee pain/discomfort symptom survey and a review of the company's OSHA 300 log to pinpoint areas of concern where MSDs may exist or develop. To promote the evaluation of this study and to accomplish the established goals, anthropometric values/data examined to ensure an optimal fit between the workers and the wig-wag machine design. This chapter discusses the methodology for collecting and analyzing the data to complete this study, in addition to a description of the procedures for selecting the subjects and the instrumentation utilized.

Subject Selection and Description

The subjects of this study were selected by the management of Company XYZ which was based on the task that, according to the safety director, possesses the most potential for causing MSD injury. Thus, only four wig-wag machine operators served as subjects in this study. After the subjects were identified, the researcher clearly explained the purpose of the study to them. The participants were also informed that they would be recorded on video while they performed the job, and no names or personal information would be revealed in the study. After the subjects agreed to participate, the researcher explained all the documents they needed to complete to participate in this study, including the consent form (approved by the IRB of UW-Stout) (see Appendix E) and the symptom survey content. A consent form was provided to the participants to be reviewed and signed in order to obtain their permission before collecting the data. The participants were allowed to ask any questions during the explanation of the consent form and the symptom survey. Finally, the researcher informed the subjects that all the obtained data and documents would be used only by the researcher for the purposes of this study.

Instrumentation

In this study, a variety of ergonomic risk assessment tools were utilized to aid in the identification of ergonomic risk factors associated with the current process of the wig-wag machine which include REBA assessment, the ergonomic task analysis worksheet, the employee symptom survey, and a review of available regulatory injury/illnesses records. The REBA worksheet was utilized to identify and assess awkward postures associated with the task. An ergonomic task analysis worksheet was also used to assess a wider range of ergonomic-related risk factors that the REBA worksheet did not address. To promote the accuracy of measurements, instruments such as digital video cameras and a manual goniometer were utilized. A video recording was made of each task so that the activity could be played several times at different paces to help identify all the ergonomic-based risk factors present. The manual goniometer then was used in conjunction with the video recording to measure joint angles, in degrees, between two adjacent body segments. A normal tape measure was also used to measure workstation-based data which included structural and functional measurements and minimum and maximum dimensions. Then the measurements were analyzed against the anthropometric table of U.S anthropometric data, inches (Champney 1979; Muller-Borer 1981; NASA 1978) (Chengalur et al., 2004) (see Appendix D).

Data Collection Procedures

After the subjects were identified and agreed to participate, they were asked to perform their respective tasks as they would during a normal day. The researcher visually observed the job in which four wig-wag machine operators were loading the bins with the rubber/polymer strips. Furthermore, the company's safety director filmed the procedures using a hand-held digital camera. Approximately 30 seconds of the total exposure time was recorded, showing the subjects' whole bodies as they were used to perform the task. Then, the researcher reviewed the video to collect data, utilizing the previously mentioned ergonomic assessment tools. Following are detailed descriptions of the data collection procedures used in this study.

Rapid Entire Body Assessment (REBA)

The REBA assessment worksheet was used to assess body postures associated with the wig-wag machine process. After observing the task, both upper and lower extremities (neck, trunk, leg, upper arm, lower arm, and wrist postures) were evaluated in which each body segment was given a score based on range of motion. Then, the final REBA score was calculated and compared to the scale of corrective actions provided in the worksheet, which was used to derive recommendations and suggestions. The REBA worksheet includes five levels of corrective actions which involve the following:

- Action level 1. A score of 1 indicates that the posture is acceptable.
- Action level 2. A score of 2 or 3 indicates a low risk, and change may be necessary.
- Action level 3. A score of 4 or 7 indicates a medium risk, and further investigations and changes are necessary soon.
- Action level 4. A score of 8 to 10 indicates a high level of risk, and a need for immediate investigation and implementing changes.
- Action level 5. A score of 11 and higher indicates that significant risk is involved and require immediate implementation of changes.

Ergonomic Task Analysis Worksheet

After the researcher observed the task and became familiar with the process, an ergonomic task worksheet was utilized to identify all the associated ergonomic risk factors including repetition, posture, vibration, reaching/proper height, force, static load, and other environmental risk factors such as noise, lighting, temperature, work pace and floor surface. Based on the severity of the observed risk factor and in reference to the drawing provided on the worksheet, each risk factor was evaluated and scored within three levels: ideal (1, 2, 3…30), warning level (1A, 2A, 3A….30A), or take action (1B, 2B, 3B…30B). While the ideal level means that there is no risk associated with the performed task, both the warning level and take action level indicate that a risk factor is present. The distinction between warning and take action levels is that the latter possesses the highest risk level, where immediate action is required to eliminate the identified ergonomic risks.

Employee Symptom Survey

This study utilized a pain/discomfort symptom survey developed by the University of Wisconsin-Madison (see Appendix C). The survey is two pages long and was selected because it can be completed quickly and easily by the subjects. The survey includes short questions that help identify employees' discomfort and areas where MSD injury may develop or already be present. Also, the survey sheet utilizes a body parts map where the subjects were asked to mark the body parts or limbs that they are experiencing pain or discomfort. Four wig-wag machine operators were involved in this survey. The researcher handed a survey sheet to each participant after explaining its content. The participants were asked to complete the survey, and, in order to ensure privacy, place the form in an envelope and return it to the safety director, to be collected later by the researcher.

Review of Available Records

In this study, a review of the company's injury and illness records was conducted as a starting point of worksite analysis to evaluate the scope of risk factors and trends of MSDs. This step included a comprehensive review of the company's OSHA 300 log for the past three years.

The company's safety director provided the researcher with an OSHA 300 log that did not contain any of the employees' personal information. However, information pertaining to tasks or activities was indicated to help direct attention to existing and potential areas of increased risk. The review of this data will promote the identification of injury/illness, aid prevention efforts, and provide statistical data to guide interventions, prioritizing and evaluating tasks after implementing controls to ensure the efficiency of the interventions.

Anthropometry

Workstation measurement data was collected in this study to ensure optimal fit between the workers and the wig-wag machine design. Per guidelines which were provided by Tayyari and Smith (1997), following is a description of the procedures that were used to collect and analyze the workstation measurement data:

- Defining the equipment's users which included four wig-wag machine operators.
- Identify the proportion of the population which will be accommodated to the 95 percentile.
- Identify the body dimensions necessary for the design, such as upper and lower arm length, leg length, and kneeling height.
- Determine the accommodation type, whether a reach or clearance situation. In this study, the accommodation types included both situations, since the operators performed the job while standing, which involved reaching forward and backward.
- Measure the population to determine where these individuals are situated in relation to the 95^{th} percentile range which is listed in the anthropometric tables.
- Consider the type of clothing or personal protective equipment involved in order to identify the necessary allowance. Both shoes and helmet dimensions were accounted for (one inch was added for the shoes and one inch for the helmet).

Utilizing a normal tape measure, the researcher measured both structural dimensions (the body's physical dimensions), such as upper and lower arm length leg length, foot length, and hand length, and functional dimensions (dynamic), such as the range of joints movement and kneeling height. Using the same tool, the workstation-based data was collected to ascertain both minimum and maximum dimensions. For minimum dimensions, a high percentile value (95^{th}) was chosen to represent the minimum allowable dimensions (clearance) needed to accommodate the largest population. On the other hand, for maximum dimensions, a low percentile value (5^{th}) was chosen to determine the maximum allowable dimensions (reach) needed to accommodate the smallest population. By doing so the workstation will be assessed with the intention of accommodating the smallest (5^{th}) and the largest (95^{th}) of the population. The collected data (vertical and horizontal demand of the workers) was then analyzed and benchmarked against the anthropometric table of U.S anthropometric data, inches (Champney 1979; Muller-Borer 1981; NASA 1978) (Chengalur et al., 2004) (see Appendix D).

Data Analysis

As previously indicated, approximately 30 seconds of the employees' total work time on the wig-wag machine was recorded on video for analysis. A manual goniometer was utilized in conjunction with the video recording of the task being analyzed to measure joint angles, in degrees, between two adjacent body segments. Identifying joint angles associated with a task is important for the ergonomic risk assessments and for comparing the task before and after interventions are implemented. This study used a traditional manual goniometer that is comprised of two extended arms where the stationary arm is aligned with the central axis of one body segment, while the other arm is placed on the central axis of the adjacent limb. The degree between the endpoints indicates the entire range of motion associated with the task under analysis. In order to accomplish this step, the video recording was paused. The video-based data was also utilized to identify and assess ergonomic risk factors related to the wig-wag machine process, such as awkward posture, repetition, force, duration and temperature extremes, by using REBA assessment and the ergonomic task analysis worksheet. Quantitative data was derived from the employee symptom survey which specified areas of concern related to the development of MSDs or employee discomfort. Loss analysis was also performed by reviewing the company's OSHA 300 log of the past three years to identify reported illnesses and injuries, and areas where potential injury or illness may develop. No employees' names or personal information was mentioned in the company's OSHA 300 log that was provided by the safety director to the researcher. The collected workstation-based data (vertical and horizontal demand of the workers) was then analyzed and benchmarked against the anthropometric table of U.S anthropometric data, inches (Champney 1979; Muller-Borer 1981; NASA 1978) (Chengalur et al., 2004) (see Appendix D) from which the researcher was able to identify the appropriate fit (dimensions) and eventually derive reasonable recommendations.

Chapter IV Results

The purpose of this study was to analyze the ergonomic-based risk factors which were present for workers using the wig-wag machine at Company XYZ and then to assess the factors' contributions to work-related musculoskeletal disorders (WMSDs). In order to achieve this purpose, several goals were established which include the following:

- Perform an ergonomic workstation analysis utilizing the Rapid Entire Body Assessment (REBA).
- Quantify the extent of posture, force, repetition, duration, and temperature extremes with an ergonomic task analysis worksheet.
- Perform a review of the company's OSHA 300 log to determine the frequency of the ergonomic-based risk factor which relate to the wig-wag process.
- Administer an employee symptom survey to quantify the extent of pain or discomfort that employees are experiencing.
- Conduct an anthropometric study to assess with the intention of accommodating the smallest (5^{th}) and the largest (95^{th}) percentiles of the population to ensure and achieve optimal fit between the wig-wag operators and the machine.

The methodology to collect data involved using a variety of ergonomic risk assessment tools that aid in the identification and analysis of ergonomic-based risk factors associated with the current process of the wig-wag machine. The REBA worksheet was utilized to identify and assess awkward postures associated with the task. The ergonomic task analysis worksheet was also used to assess a wider range of ergonomic-related stressors that the REBA worksheet did not address. To promote the accuracy of measurements, video recording and still photography were used in conjunction with a manual goniometer which measures joint angles, in degrees, between two adjacent body segments. The pain/discomfort symptom survey was used to assist in the identification of employees' pain/discomfort and areas where MSD injury may develop or already be present. A review of the company's OSHA 300 log for the past three years was also performed to promote the identification of injuries/illnesses and aid in the eventual development of prevention efforts. Further, workstation measurement data (vertical and horizontal demands of the workers) was collected to be examined and benchmarked against the U.S anthropometric data (Champney 1979; Muller_Borer 1981; NASA 1987) (Chengalur et al., 2004) (see Appendix D) to ensure an optimal fit between the workers and the wig-wag machine design.

Presentation of Collected Data

Objective one. The first goal of this study was to perform an ergonomic workstation analysis utilizing the Rapid Entire Body Assessment (REBA) (see Appendix A). The REBA worksheet allowed the researcher to analyze neck, trunk, leg, upper arm, lower arm, and wrist postures. Furthermore, the accompanying force, coupling, static posture and repeated movements are all were considered to calculate the final REBA score. This step was performed using a video recording of the respective task to thoroughly identify all the associated risk factors with each body segment as the activity could be played at different paces and paused several times. Furthermore, a manual goniometer was used in conjunction with the video recording to measure joint angles, in degrees. Note that a specific joint or body part may encounter movement at different ranges. However, the angles values indicated in the worksheet were based on the worst-case scenario (most significant movement). Table 1 below displays the score for each body part as well as the final REBA score.

Table 1

REBA Score of the Wig-Wag Operators

REBA	Neck score	Trunk score	Leg score	Score A	Upper arm score	Lower arm score	Wrist score	Score B	Score C	Activity score	Final score
Wig-wag process	2	3	1	4	4	2	2	8	8	1	9

As indicated above in Table 1, the final REBA score of the wig-wag machine operators was 9, which indicates a high level of risk and a need for immediate investigation and implementing changes. The neck and the trunk scores were high (2 and 3) since the workers were required to perform the job while standing on a low work surface height and thus they assumed neck flexion at approximately 20° and forward spine flexion of 60° from vertical. The leg score was 1 since such posture was maintained a relatively neutral posture. Score A included the sum of the neck, trunk and leg scores, yet the force/load score was not involved since the associated load was less than 11 pounds. A score of 4 was recorded for the upper arm position since the workers were frequently required to reach above their shoulders height and assume shoulder flexion at approximately 110° (as the most significant movement). Also, the operators experienced elbow flexion at 105°, and wrist extension at approximately 15° that was associated with hand pronation. Thus, this movement resulted in score of 2 for both the lower arm position and the wrist posture. The hand-hold or coupling was observed to be poor, thus, 2 was added to the B score to yield a score of 8. The activity score was 1 since the process of the wig-wag machine involves repeated small range actions (more than 4 times per minutes). In order to calculate the final REBA score, the activity score was added to the Table C score (upper [A] and lower [B] extremities scores) to acquire a score of 9 which indicates, based on the REBA's five levels of corrective actions, a high level of risk and a need for immediate change to the current process to avoid the risk of musculoskeletal disorders.

Objective two. The second objective of this study was to quantify the extent of posture, force, repetition, duration, and temperature extremes with an ergonomic task analysis worksheet (see Appendix B). This assessment method covers a wider range of ergonomic-based risk factors which include vibration, reaching/proper height, static loading, and other environmental risk factors such as noise, lighting, work pace, and floor surface, in addition to the previously identified in REBA assessment. Each risk factor, in reference to the drawing provided in the worksheet, was evaluated and scored within three levels which include ideal (1, 2, 3…30), warning level (1A, 2A, 3A….30A), or take action (1B, 2B, 3B…30B). A summary worksheet of the identified ergonomic-based risk factors associated with the wig-wag process and the score for each factor is provided in the later part of Appendix B. Note, the evaluation of such risk factors was based on the worst-case scenario (most significant of what was observed during the workstation assessment process).

The completed summary worksheet which is presented in the later part of Appendix B displays that the repetition risk factor was assessed to be at the warning level (1B) since the wig-wag process requires excessive repetition of the hands or arms movement. The average repetition rate of a single hand was observed to be approximately 30 times per minute. The standing posture was scored in the take action column (2B) since the operators were required to maintain a spine flexion while in the standing posture. Since the operators perform the task while standing and no sitting was involved in the process, the sitting posture scored ideal (3). However, the score of head/neck posture was in the take action category (4B) since the workers typically need to flex the cervical portion of their spine while performing the task. No cervical/neck bending backward, sideways or twisting was involved and thus these postures were scored in the ideal column. The process of the wig-wag machine requires frequent hand/arm rotation less than 20°, thus, the hands posture risk factor was scored in the warning column (5A). The wrist posture was determined to be at the warning level for extension/flexion deviation (6A). Since no hand, arm or whole body vibration was involved, the vibration risk factor scored ideal (7 and 8). Given that the workers had to frequently reach above their shoulders height and assume shoulder flexion at approximately 110°, the reach/proper height element was scored at take action level (9B). Also, during the reach process, the workers were observed to assume elbow flexion up to 105° which scored such posture in the warning column (9C). Neither twisting nor bending/reaching to the side was involved, thus, the score for both was considered ideal (10). However, the bending/reaching forward risk factor score was assessed in the take action level (10B) as the employees experienced an excessive reach forward or spine flexion at approximately 60° in order to place the rubber strips at the bottom of the bins in an orderly manner. The operation of the wig-wag machine does not involve the lifting of objects, therefore, the force risk factor was scored as ideal (11 and 12). The workers' fingers and thumbs do not comfortably fit around the object (rubber strip), and moderate pinch grip was experienced, so the pinch grip category scored at the warning level (13A). The score of slipperiness was determined to be ideal (17), even though gloves were needed to be worn and fit well. This is because the coefficient of friction between the rubber strips (object) and the workers' hands appeared to be adequate. Since there was no constant position or tool/object that needed to be held for more than six seconds, the static loading factor was scored as ideal (18). However, the wig-wag job required the use of the same body parts/muscles and motion for an extended period of time (more than 50% of the task is repetitive). This would increase the likelihood of fatigue to the soft tissues and muscles. Based on this, the repetition risk factor was determined to be at the take action level (19B). For the work environment, the work pace scored warning (24A) as the workers had no control on such. The workstation possessed sufficient lighting (25) and the temperature was fair (26), thus, both were scored at the ideal level, while the noise risk factor was assessed at the warning column (27A). The floor surface score was at the warning level for both (28) and (29) because it does not provide adequate traction and is not padded, which may contribute to slight stress on the back and legs. Moreover, since the task requires standing for prolonged periods of time (standing more than 50% of the task duration), additional stress could be introduced to the back and legs, so the task was scored in the take action column (30B).

Objective three. The third objective of this study was to perform a review of the company's OSHA 300 log to determine the frequency of injuries caused by the ergonomic-based risk factors and related to the wig-wag process. This review will also help direct attention to potential and existing areas of risk and assist in evaluating the task after implementing controls (Putz-Anderson, 1988). A review of the company's injury/illness records indicated that three ergonomic-based injuries related to the wig-wag operation have occurred during the past three years. Table 2 displays the ergonomic injuries that occurred during the past three years.

Table 2

Ergonomic Injuries Related to the Wig-Wag Process

Employee	Date	Type of Injury/Illness	Case Classification
1	1/18/2011	Right shoulder strain	Remained at work/other recordable cases
2	9/6/2011	Right hand, finger, wrist strain/sprain	Remained at work/other recordable cases
3	11/6/2012	Lower back injury	Remained at work/other recordable cases

Table 2 illustrates that two OSHA recordable injuries occurred in 2011, while one injury was recorded in 2012. However, the researcher also reviewed the injury records for 2010, but no ergonomic-based injuries/illnesses related to the wig-wag machine occurred during such time. As the table displays, all the injuries occurred in the upper extremities. One case involved right shoulder strain, which is believed to be due to the highly repetitive motion and overexertion of shoulders and arms in addition to the awkward posture involved in the task. The lower back injury may also be due to the excessive spine flexion that the workers experienced when they performed a forward reaching motion. The hand, finger, and wrist strain/sprains were diagnosed as cumulative trauma disorders resulting from the continuous use of the same body parts and the awkward postures associated with the task. The case classification column displays that all the injured employees remained at work and none of the injuries caused days away from work or job transfer. However, all the identified OSHA recordable injuries were significant due to the undesirable consequences they may contribute to direct losses associated with increased worker compensation and medical care costs, and indirect costs associated with lost worker time.

Objective four. The fourth goal of the study was to administer an employee symptom survey to quantify the extent of pain or discomfort that employees experience. The collected data also helps identify the number of employees who experienced pain/discomfort and then determine areas where ergonomic-related risk factors may exist. A two-page pain/discomfort symptom survey developed by the University of Wisconsin-Madison (see Appendix C) was used in this study. Four wig-wag operators were involved in the questionnaire. The survey first asked the participants the amount time they have been on the wig-wag job. Of the four participants, three employees' answers were greater than five to ten years, while one employee answered less than three months. Next is a "yes" or "no" question which asks the survey-taker if any pain or discomfort have been experienced during the last year. If the answer is yes, then the participants shade in the area of discomfort or pain on the provided drawings and then complete the questions in the next page. If the answer is “no,” the employee does not need to shade in the drawings or to complete the second page. For this question, it should be noted that all the participants indicated they have experienced pain or discomfort during the last year.

The employees who answered “yes” in the previous question moved to complete the second page. The first question on the second page is a multiple choice and asks the employees to check area/areas where symptoms are present. The choices are neck, elbow/forearm, upper back, thigh/knee, fingers, shoulder, hand/wrist, low back, lower leg and/or ankle/foot. The following question relates to previous one and asks the participants to choose the word that best describes the pain/discomfort indicated in the first question. The answer options are aching/cramp, numbness/tingling, stiffness, burning, pain, weakness, loss of color, swelling or other. Table 3 summarizes the participants’ responses for both questions one and two.

Table 3

Answers to Question one and Two

Employee	Location of Pain or Discomfort	Symptom/s of Pain or Discomfort
1	Left and right shoulders Low back	Aching/cramp
2	Right shoulder	Aching/cramp Stiffness Burning
3	Upper back Hand/wrist	Aching/cramp Stiffness
4	Low back Left shoulder	Stiffness

The results in Table 3 indicate that three workers experienced discomfort in the shoulder region. The first employee reported an aching/cramp in both left and right shoulders, and the second worker indicated aching/cramp, stiffness and burning in the right shoulder, while the third case involved stiffness in the left shoulder. These answers correlate to the REBA result for the upper and lower-arm postures and the repetitive-motion score in the ergonomic task analysis worksheet in which take action level was recorded. The table also displays that one worker is experiencing low back aching/cramp, and another is experiencing stiffness in the same region. Only one participant reported that he/she suffered from aching/cramp and stiffness in the hand/wrist and upper back area.

The third question of the survey addresses when the participants first noticed the problem. The first respondent indicated that the problem occurred within the past three months, which was the same period since he/she started the wig-wag job. One employee responded within six to eight months, and another respondent reported that the problem occurred within the past year. Only one participant did not answer the question due to uncertainty.

The fourth question is a multiple choice and asked “how long did each episode last?” The possible choices were less than one hour, one hour to 42 hours, 24 hours to one week, one week to one month, one to six months, or more than six months. Two participants answered that each episode lasted from one hour to 24 hours, while the other two respondents indicated 24 hours to one week.

The fifth question of the survey was also related to the episode of the experienced problem which asked the participants about the number of the separate episodes they have had in the last year. Only two participants answered the question, and the other two respondents did not due to uncertainty. One employee mentioned that he/she felt such pain/discomfort every day during the last year, and the other respondent’s answer was from six to twelve times. Question seven was a “yes” or “no” question which asked the survey-takers if they had the problem in the last week. Only two participants answered “yes” to this particular question.

In the sixth question, the respondents were asked about their perspectives of the cause of the problems. All the answers indicated repetitive motion and awkward posture as causes. The participants responses were "bending and reaching," "repetitive bending," "repetitive usage," and "repetitive reaching and bending." The employees' answers can be linked the results of the REBA and the ergonomic task analysis worksheets in which such risk factors' scores were high and reflect an elevated level of risk to cause a WMSD.

Question eight allows the respondents to rate the level of the experienced physical discomfort problem in both its current and worse levels. The participants were asked to mark "X" on a pain/discomfort scale between "none" and "unbearable." For the current feeling of discomfort, three of the responses were at the mild level, and only one employee reported a moderate discomfort. For the "it's worse" scale, three participants reported a severe level of discomfort, while only one respondent indicated a moderate level on the scale.

For questions number nine, ten, eleven and twelve, none of the participants indicated that they have received medical treatment for the felt pain or discomfort. Also, none of the respondents reported a time lost from work, modification in such duty, or changed jobs due to the present problem. Even though the losses have not occurred yet, the results indicated a significant risk associated with current practices which may lead to undesirable consequences.

Objective five. The fifth goal of this study was to perform an anthropometric study on the wigwag machine/workstation. Cursory observations indicated that the wig-wag workstation design does not fit its occupants. Therefore, the anthropometric analysis attempted to maximize the fit or the relationship between the wig-wag operators and the machine. It was observed that the wig-wag operators perform the job while standing and assume a repetitive reach horizontally and vertically when they load the large bins with the rubber strips. These bins are constructed from galvanized steel or aluminum with dimensions of 39" in heigh, 60" in length and 46" in width with the average bin weighting 1,000 pounds (including the rubber weight). The wig-wag operators' body's physical measurements, or static dimensions, were measured utilizing a standard tape measure. These measurements are presented and compared to the U.S anthropometric data, inches (Champney 1979; Muller_Borer 1981; NASA 1987) (Chengalur et al., 2004) in Table 4. The measurement column in the table below correlates to the body parts drawings provided in Appendix D which displays the anthropometric dimensions of standing, sitting, hands, face and foot.

Table 4

Wig-Wag operators' Bodies Physical Dimensions and U.S Anthropometric Data

Measurement	U.S anthropometry data			Employee 1	Employee 2	Employee 3	Employee 4
	5th	50th	95th				
1a	27.2	30.7	35.0	32	37	32	38
1b	22.6	25.6	29.3	24	26	24	26
1c	19.1	24.1	29.3	27	29	27	29
2	7.1	8.7	10.2	12	12	13	12
3	37.4	40.9	44.7	37	43	39	40
4	15.3	17.2	19.4	20	24	20	24
5	25.9	28.8	31.9	29	31	29.5	32
6	38.0	42.0	45.8	42	46.5	44	47
7	48.4	54.4	59.7	54	60	58	61
8	56.8	62.1	67.8	62	69	64	70
9	60.8	66.2	72.0	68	73.75	68	75
10	74.0	80.5	86.9	81	92.5	86	93
26	8.9	10.0	11.2	9	12	12	13

27	3.2	3.7	4.2	4.0	5.0	4.5	5.25
28	1.0	1.2	1.4	1.75	2.0	1.5	2.25
29	6.7	7.4	8.0	6.5	8	7.75	8.0
30	2.3	2.8	3.3	3.0	3.0	3.0	3.0
31	2.8	3.2	3.6	3.1	3.5	3.5	4.0
32	3.8	4.7	5.6	5	5.5	5.5	6.0
33	0.7	0.8	1.0	1.0	1.0	1.0	1.0
34	0.6	0.7	0.8	0.5	0.75	0.75	1.0
38	5.4	5.9	6.3	7.0	7.0	6.25	7.25
39	2.1	2.4	2.6	2.0	2.5	2.5	2.0
40	3.3	3.6	3.9	4.0	4.5	4.0	4.5

Table 4 displays the U.S anthropometric data (Champney 1979; Muller_Borer 1981; NASA 1987) (Chengalur et al., 2004) and the four wig-wag operators' bodies dimensions for comparison. The body physical measurements, or static dimensions data, would be more useful if the respective job is stationary or static, but such will help the researcher in analyzing the horizontal and vertical job demands and providing recommendations. However, since the wig-wag job requires the frequent movement of various body parts, especially hands, the main focus of this anthropometric study will be on the functional (dynamic) data. At the beginning of the bin loading process or while placing the rubber strips on the bottom of the bins, the employees' hands were positioned below the hip height. They also assumed a forward spine flexion at 60° in order to lay the rubber strips in an orderly manner on the bottom of the bins. The operators also were observed to experience a repetitive amount of upper arm (shoulder) flexion from approximately 100° down to 20° while the spine was flexed. However, when working on the top part of the bins (higher level), it was obvious that the workers positioned their arms repeatedly above the shoulder height and experienced shoulder flexion at an angle of approximately 110° while the spine was flexed at 25°. During this stage, the vast majority of the workers were observed to utilize a flexed neck at approximately 20°. Additionally, the horizontal forward reach distance beyond the worker's abdomen while the spine is flexed was 35" which was measured during the beginning of the bin loading (as the most significant). The initial height that the worker grasps the ribbon of materials is generally acceptable for his/her stature. However, the act of guiding the ribbon causes him/her to repeatedly extend his/her shoulders below the waist height.

The collected data (vertical and horizontal demands of the workers) was then analyzed and benchmarked against the anthropometric table of U.S anthropometric data (in inches) (Champney 1979; Muller-Borer 1981; NASA 1978) (Chengalur et al., 2004) (see Appendix D). For minimum dimensions, a high percentile value (95th) was chosen to represent the minimum allowable dimensions (clearance) needed to accommodate the largest population. On the other hand, for maximum dimensions, a low percentile value (5th) was chosen to determine the maximum allowable dimensions (reach) needed to accommodate the smallest population. By doing so the workstation will be assessed with the intention of accommodating the smallest (5th) and the largest (95th) of the population. Based on the analysis, the forward functional reach (abdominal extension) was identified to be 19.1". This estimate was based on the 5th percentile (see Appendix D) to indicate the maximum allowable distance for forward reach envelopes so that the shortest population can reach the objects without assuming a spine flexion postures. The major difference between the ideal forward reach distance (19.1") and the actual worksite measurement (35") forces the workers to experience an excessive spine flexion posture which has a significant contribution to WMSDs such as low back pain. When measuring the highest and the lowest vertical reach distance, it was essential to consider that the workers should not be required to reach above their shoulders or below the hips. Therefore, 48.4" was the highest allowable vertical reach distance which was based on the 5th percentile (see Appendix D) to accommodate the smallest population and eliminate the need for shoulders flexion. The lowest vertical reach distance was found to be 44.7" which was based on the 95th percentile (Appendix D) to accommodate the largest population so that the workers can reach the objects while standing without assuming a spine flexion. It should be noted that the previous anthropometric shoulder and waist heights are based on a 50/50 mix of males and females population. The workstation vertical and horizontal reach demands should therefore not exceed the previously identified values, which were derived from anthropometric table of U.S anthropometric data, inches (Champney 1979; Muller-Borer 1981; NASA 1978) (Chengalur et al., 2004) (see Appendix D) in order to prevent fatigue and eliminate/minimize pain or discomfort.

Discussion

The final REBA assessment score of 9 indicated that several risk factors are present that may significantly contribute to MSDs in both upper and lower extremities. The upper-extremity scores were high, which causes a concern. For instance, the workers' trunk position was observed to experience a spine flexion posture at 60°, which has the potential to cause low back injuries. Moreover, awkward postures were noticed in the neck region, since the work surface level is low and the operators are required to maintain a cervical spine flexion around 20° as they perform the job. A significant burden was placed on the workers' upper/lower arms and the wrists due to the awkward postures and overuse of the same body components when grasping the rubber strips and reaching forward to load such in the bins. Due to this unacceptable movement and the poor coupling/grip, score B was high (8) which indicates a great risk of developing a musculoskeletal injury/illness in associated muscles, nerves and/or other soft tissues. The REBA assessment pinpointed various awkward postures of different body parts which could easily contribute to cumulative trauma disorders (CTDs). These disorders may not be visible in early stages and develop slowly over a long period of time and thus it is difficult to recognize such until chronic symptoms arise (Chengalur et al., 2004). However, these disorders can occur as the result of exposure to a single risk factor, and the risk level is aggravated if two or more ergonomic risk factors are combined. Furthermore, the consequences of the identified risk factors are not limited to safety and health aspects. Such disorders can place a significant economic burden on Company XYZ due to the costs of medical treatment and worker compensation. Therefore, based on the REBA assessment, the current process of the wig-wag machine highlighted that investigation and changes must be implemented to avoid undesirable consequences.

The task analysis worksheet addressed various ergonomic-related risk factors in addition to the previously identified in REBA assessment. The inspection indicated that extremely repetitive hand and arm movements were involved in the process. Each wig-wag operator was observed to perform an average of 30 repetitive movement per minute while loading the rubber strips in the bins. As pointed out in Chapter II, overexertion and overuse of the same body part, especially over a prolonged work periods, will cause fibers of soft tissues to fray or tear apart which leads to musculoskeletal injuries similar to tendinitis. Moreover, highly repetitive movement of hands or fingers may cause the synovial sheath to accumulate excessive amounts of fluid, thus leading to pain and swelling which contributes to a tenosynovitis-based disorder. Highly repetitive movement of the hands and arms, especially around the wrists, has great potential to cause carpal tunnel syndrome (CTS), in which the finger flexor tendons that pass through the carpal tunnel become irritated or swollen and then the median nerve becomes compressed (Putz-Anderson, 1988). This will impair the sensory and motor functions of the hand and cause pain, numbness, and tingling in the palm and fingers (Tayyari & Smith, 1997). It is believed that the risk of CTD injury among wig-wag operators is high since the repetitive motion was also associated with other risk factors such as prolonged work durations and awkward postures.

It should be noted that other awkward and unhealthy movements were observed which may contribute to the occurrence of WMSDs. Due to the inappropriate workstation design, the workers need to frequently reach above shoulder height to grasp the rubber strips that leave the machine, and then reach below hip level to guide them in the bins. While doing so, the workers were observed performing various unacceptable postures which include thoracic spine flexion at 60°, cervical spine flexion (neck forward flexion) at 20°, repeated shoulder flexion at approximately 110°, and wrist flexion/extension of up to 20°. These awkward postures will force a joint to move beyond its normal range and exceed its limitations, which significantly leads to CTD. Moreover, if a muscle is not maintained within the range of its neutral posture, its maximum output is lowered, which elevates the risk of fatigue or injury (CDC & NIOSH, 2009). In terms of posture, it was also observed that the process of loading the bins requires prolonged standing which indicates another area of concern. Activities that involve excessive standing durations have the potential to cause localized-muscle fatigue, especially in the gastrocnemius muscle which is located in the back part of the lower leg (Bridger, 2009). Additionally, the absence of anti-fatigue mats (discussed in Chapter two), increases the risk of fatigue or discomfort in the lower leg, feet, and back (Bridger, 2009). In fact, lower back injury is of great concern in this case. Company XYZ's safety director indicated that most of the wig-wag operators suffer from lower back pain, and the total cost associated with one back injury could easily exceed $54,200. Moreover, the Bureau of Labor Statistics (BLS) indicated that back injuries constitute one out of every five workplace disorders and leave more than a million workers in pain each year (cited in Environmental Safety, 2005). However, performing tasks while the back is flexed, horizontal reaching for distant objects, reaching above the shoulders, and prolonged work durations are all risk factors associated with the wig-wag process and thus present an increase the risk of back injury (Tayyari & Smith, 1997). Furthermore, standing can easily stress the intervertebral disks, especially those which are located in the lumbar region. Since the average age of the wig-wag operators is 49 years, the risk of low back injury is greater because the spinal disks become weaker and less resilient with age (Tayyari & Smith, 1997).

The review of the OSHA 300 log for the years 2010, 2011, and 2012 identified that three ergonomic-related injuries occurred which could be attributed to the wig-wag process. All the recordable cases affected the upper extremities including the back, shoulders, fingers, wrists and hands, which the workers utilize continuously when they perform their respective jobs. This review aligns with the result of both the REBA and ergonomic task analysis worksheet assessments. The REBA assessment indicated a high score for the upper extremity. The ergonomic task analysis worksheet scored the repetitive motion and awkward postures of most upper limbs in the take-action columns. These results explain why most of the recordable injuries occurred in the upper extremities. Company XYZ should be aware of the previous injury cases and use such as indicators for risk in order to avoid undesirable consequences that could interrupt production. These consequences may contribute to direct losses in the form of worker compensation and the cost of medical care, indirect costs associated with lost work time, employee replacement and training, and lowering productivity and quality. For instance, the total cost associated with one shoulder injury, according to the facility safety director, could easily surpass $20,000, and the total cost associated with one back injury could easily exceed $54,200 as previously mentioned. In fact, the identified cases in the log are classified as cumulative trauma disorders which means that these types of disorders develop gradually over time rather than as a result of a single accident such as a slip or fall (Putz-Anderson, 1988).

Another dilemma of CTDs is that they are not visible and develop slowly over a long period of time, so people cannot recognize such injuries or illnesses until chronic symptoms arise. However, pain, abnormal or limited joint movement, and tissue swelling are considered the most reliable symptoms of CTDs, which help to identify such injury and illness before it becomes chronic (Putz-Anderson, 1988). In this regard, it appears that cooperation between workers and management is needed to improve the reporting of early symptoms before they cause chronic or recordable injuries.

All four wig-wag operators participated in the pain/discomfort symptom survey which identified areas where WMSD injuries/illnesses may exist and identify the number of employees who experience pain/discomfort. The collected data also supported the identification of ergonomic-related risk factors associated with the current process (Putz-Anderson, 1988). The survey results indicated that all of the wig-wag operators are experiencing pain/discomfort symptoms. Two instances involved shoulder discomfort, three participants suffered from back pain, and one respondent reported symptoms in the hand/wrist region. The symptoms varied from worker to worker; however, aching/cramp and stiffness were the most reported. The result of the pain/discomfort symptom survey correlates with the REBA and the ergonomic task analysis assessments. Both assessments pinpointed that the upper extremities were at a high level of risk for musculoskeletal injury/illness due to awkward postures, such as trunk flexion at 60°, and the highly repetitive motion of the upper and lower arms when performing small-range actions. In fact, the respondents' answers for question six on the survey supported this finding where all the participants indicated that the awkward posture and the repetitive use of the same body parts for prolonged periods of time were the main causes of the present problems. The pain/discomfort scale (question eight of the survey) identified that most of the participants experienced moderate to severe pain. This could also be an indication of the high level of risk associated with current job practices, which also correlates with the REBA and the ergonomic task analysis results. To date, none of the identified cases have caused time away from work, modification of the duties or a change of job. However, as indicated above, the survey, the REBA and the ergonomic task analysis assessments all pointed to a high level of risk. Moreover, as discussed in Chapter II, these work-related musculoskeletal injuries/illnesses are not visible and develop slowly over a prolonged period of time (Putz-Anderson, 1988). Therefore, if such symptoms do not received sufficient attention at the early stages, this negligence may cause burdens to the company whether from a safety and health standpoint or from a financial aspect.

One of the main applications of anthropometry is the specification of the horizontal and vertical-reach distances, and ensuring that all objects are placed within the zone of convenient reach. Within this zone, the workers can perform the job without having to assume awkward postures such as leaning forward (Bridger, 2009). In this study, the collected workstation-based data (vertical and horizontal demand of the workers) was measured and then analyzed against the table of U.S anthropometric data, inches (Champney 1979; Muller-Borer 1981; NASA 1978) (Chengalur et al., 2004) (Appendix D). The study indicated that the horizontal and vertical-reach demands of the workers were inappropriate. This mismatch between the workers' traits' and the machine design required the workers to assume various unacceptable body postures. The major difference between the ideal forward reach distance (19.1") and the actual workstation measurement (35") forced the operators to lean forward and experience extreme spine flexion at approximately 60°. To prevent the occurrence of fatigue, the forward reach distance should be reduced to an ideal level so that all the workers can reach horizontally while the spine is maintained at the neutral posture. Also, the vertical reach distance should be within the range of the shoulder (maximum) and hip (minimum) heights. The anthropometry result indicated that the highest vertical reach distance should not be higher than 48.4” and not lower than 44.7”. This way, both the smallest and the largest population can vertically reach the object without assuming unhealthy body postures such as shoulder and spine flexion. In fact, the findings of the anthropometric study align with the results of the pain/discomfort symptoms survey. For instance, most of the reported problems in the symptom survey involved back pain/discomfort, which is believed to be due to the extreme spine flexion caused by the excessive forward reach distance and by working below hip height. Moreover, all the participants indicated pain/discomfort in the shoulder region, which is also believed to be caused by the repeated shoulder flexion when the workers had to reach above shoulder height. However, the fit between the operators and the machine can be maximized through adjustments to the horizontal and vertical demand of the work, which will improve the zone of convenient reach. These adjustments will then assist in the elimination or reduction of the risk of developing a WMSD. Moreover, such adjustments are believed to help in performing the job more effectively, since work can be accomplished more effectively within the first third of the range of motion for the movement. Thus, the closer that a movement to the extreme of a worker range, the more stress which is placed on a joint and its supporting muscles (Chengalur et al., 2004).

Chapter V: Conclusions and Recommendations

The purpose of this study was to analyze the ergonomic-based risk factors which were present for workers using the wig-wag machine at the Company XYZ and then to assess the factors' contributions to work-related musculoskeletal disorders (WMSDs). In order to achieve this purpose, several goals were established which include the following:

- Perform an ergonomic workstation analysis utilizing the Rapid Entire Body Assessment (REBA).
- Quantify the extent of posture, force, repetition, duration, and temperature extremes with an ergonomic task analysis worksheet.
- Perform a review of the company's OSHA 300 log to determine the frequency of the ergonomic-based injuries/illnesses which relate to the wig-wag process.
- Administer an employee symptom survey to quantify the extent of pain or discomfort that employees are experiencing.
- Conduct an anthropometric study to assess with the intention of accommodating the smallest (5^{th}) and the largest (95^{th}) percentiles of the population to ensure and achieve optimal fit between the wig-wag operators and the machine.

The methodology to collect data involved using a variety of ergonomic risk assessment tools that aid in the identification and analysis of ergonomic-based risk factors associated with the current wig-wag process. The REBA worksheet was utilized to identify and assess awkward postures associated with the task. The ergonomic task analysis worksheet was also used to assess a wider range of ergonomic-related stressors that the REBA worksheet did not address. To promote the accuracy of measurements, video recording and still photography were used in conjunction with a manual goniometer which measures joint angles, in degrees, between two adjacent body segments. The pain/discomfort symptom survey was used to assist in the identification of employees' pain/discomfort and areas where MSD injury may develop or already be present. A review of the company's OSHA 300 log for the past three years was also performed to promote the identification of injuries/illnesses and aid in the eventual development of prevention efforts. Further, workstation measurement data (vertical and horizontal demands of the workers) was collected to be examined and benchmarked against the U.S anthropometric data (Champney 1979; Muller_Borer 1981; NASA 1987) (Chengalur et al., 2004) (see Appendix D) to ensure an optimal fit between the workers and the wig-wag machine design.

Major Findings

The REBA assessment indicated a final score of 9 for the wig-wag machine operators, which reflects a high level of risk, and a need for immediate investigation and implementation changes. The ergonomic task analysis worksheet assessment indicated that extreme repetitive hand and arm movements were involved in the process, and were associated with various awkward body postures, such as repetitive upper/lower arm flexion, spine flexion, and neck flexion, in addition to excessive work durations while standing. The review of the company's OSHA 300 logs indicated that three ergonomic-based injuries that could be attributed to the wig-wag operation occurred during the calendar years of 2010, 2011, and 2012. The pain/discomfort symptom survey results indicated that all four of the wig-wag operators experienced pain/discomfort symptoms in their upper extremities. The anthropometric analysis identified a mismatch between the workers' traits' and the wig-wag machine design (the horizontal and vertical work demands) which required the operators to assume various unacceptable body postures.

Conclusions

Based on the data collected from the results of the REBA, ergonomic task analysis worksheet, OSHA 300 log, pain/discomfort symptoms survey and anthropometric analysis, the following conclusions were reached:

- The Rapid Entire Body Assessment (REBA) was performed to evaluate the current wig-wag process and identified a final score of 9. Such a score indicates a high level of risk, and a need for immediate investigation and implementation changes. The assessment indicated that a significant burden was placed on the wig-wag operators due to the awkward postures they had to assume, such as excessive spine, upper/lower arm and neck flexion in addition to the excessive overuse of the same body components over long periods of time. The identified ergonomic-based risk factors, especially when such occur simultaneously, pose a great risk of developing a musculoskeletal injury/illness in associated muscles, nerves and/or other soft tissues (Chengalur et al., 2004).
- The ergonomic task analysis assessment indicated that current job practices require the operators to assume extreme repetitive hand and arm movements. As discussed in the literature review, overexertion and overuse of the same body part, especially for prolonged work periods, will cause fibers of soft tissues to fray or tear apart, which leads to musculoskeletal injuries similar to tendinitis (Putz-Anderson, 1988). Other risk factors including excessive work duration while standing with the occurrence of awkward body postures such as repetitive upper/lower arm flexion, spine flexion, and neck flexion were all present within the wig-wag process. To prevent the occurrence of fatigue, heavy work activities should not be sustained for more than 15 minutes, and such tasks may become risky if they are maintained for greater than this period of

time without providing the employee with breaks (Chengalur et al., 2004). Furthermore, activities that involve excessive standing durations, especially in the absence of anti-fatigue mats, have the potential to cause localized-muscle fatigue in the back region and in the gastrocnemius muscle which is located in the back part of the lower leg (Bridger, 2009). Additionally, performing tasks which involve back flexion, horizontal reaching for distant objects, reaching above the shoulders, and prolonged work durations are all risk factors associated with the wig-wag process and thus present an increased risk of back injury (Tayyari & Smith, 1997).

- The review of the OSHA 300 log for the years 2010, 2011, and 2012 identified that three ergonomic-related injuries occurred during such time which could be attributed to the wig-wag process. All the recordable cases affected the upper extremities, including the back, shoulders, wrists, fingers and hands, which the workers utilized continuously while performing their respective jobs. This review aligns with the results of both the REBA and ergonomic task analysis worksheet assessments in which the upper extremities scored an elevated level of risk.
- The employee pain/discomfort symptom survey indicated that all four of the wig-wag operators experienced pain/discomfort symptoms. Two instances involved shoulder discomfort, three participants suffered from back pain, and one respondent reported symptoms in the hand/wrist region. The symptoms varied from worker to worker, however, it should be noted that aching/cramps and stiffness were the most reported.
- The anthropometric analysis concluded that there is a mismatch between the workers' traits and the wig-wag machine design which requires the workers to assume various awkward and unacceptable body postures. Such mismatch was due to the excessive forward reach distance, the horizontal work demand, and the unacceptable vertical

reach distance that required the workers to reach above their shoulders and below the hips. Workstation-measurement data (vertical and horizontal demands of the workers) was examined and benchmarked against The U.S anthropometric data, inches (Champney 1979; Muller-Borer 1981; NASA 1978) (Chengalur et al., 2004) (see Appendix D) which is based on a 50/50 mix of males and females population. The table indicated that the horizontal-reach distance should not exceed 19.1", while the vertical-reach distance was determined to be not higher than 48.4" (shoulder height of smallest person) and not lower than 44.7" (hip height of largest person). These estimates were based on the 95th and the 5th percentile with the intention to accommodate the largest population as well as the smallest so that they can perform the job more effectively and without assuming unhealthy body postures.

Recommendations

Based on the findings of this study, several engineering and administrative-based recommendations and suggestions can be offered which would help to eliminate/reduce the presence of the ergonomic-based risk factors and their associated risks and thus lower the potential of developing work-related musculoskeletal disorders among the wig-wag machine operators.

Engineering controls:

- Implement a complete automation of loading the rubber strips into the bins, which will reduce the involvement of manual labor. In this regard, the excessive repetitive motion and overuse of hands and arms and the exposure to awkward body postures will be eliminated or at least reduced to an acceptable level. One suggested automation approach is to design and install a three dimensional distribution machine above each bin. This specific machine would not only function in a linear approach, but rather in three additive components. The three components consist of length, width and height of the bin, which would be represented by symbolic values of x, y and z. The rubber strips would be positioned horizontally in relation to the distributer, which then would deposit such into the bin in orderly manner. Another approach to automate the process is to design a system where the rubber strips would be rolled onto a sleeve connected to a spindle that rotates and collects/winds the rubber into rolls. Such systems would eliminate the need for workers to guide the rubber into the boxes, thereby reducing injuries and increasing production rate.

- Enable the bin to be adjustable from a height standpoint to eliminate the need for static flexion of both neck and spine which the workers were required to assume while standing and working on low-level work surfaces. Ideally, any given worker should not be repeatedly required to reach above the shoulders or below the waist levels. This can be accomplished by utilizing a mechanical or scissor-based lift which will allow the operator to adjust/customize the bin level to his/her personal height. Thus, such approach will reduce/eliminate the risk of static neck and/or spine flexion and provide the employees efficient work environment.
- Adjust the work vertical-reach demand in a manner that does not require the operators to work above shoulder or below hip height when grasping the rubber strips. This can be accomplished by providing depressible bins instead of the currently used ones. Such bins could possess an adjustable base that automatically travels down as more material is added and rises when such is unloaded. This approach will help to maintain the neutral posture of the

upper/lower arm and eliminate the need of excessive spine flexion which possesses a significant contribution to the occurrence of MSDs.

- Reduce the required horizontal-reach distance to an amount that enables the wig-wag operators to reach forward and place the rubber strips in the bins without assuming an awkward and unhealthy body posture such as spine flexion. In order to better exemplify the recommendation, the bins capacity should be altered to a smaller scale in terms of width, the side that is parallel to the movement of the hands. In addition, the operators should be provided freedom of mobility around the bin which would allow easier access to the desired point. This approach will not only promote the neutral body posture, but also allows operators to complete the task in a timely and convenient manner.
- Avoid activities that require excessive work durations, especially while standing, and allow the work to be performed in standing as well as seated positions. Activities with excessive standing durations possess a potential to stress the lower back and can cause localized-muscle fatigue, especially in the gastrocnemius muscle, which is located in the back part of the lower leg.
- To assist in maintaining the neutral body posture while standing, provide a space for feet or toespace. Absence of toespace forces the worker to stand away from the work surface, which can place more stress on the spine. Fatigue can develop as a result of flexing the lumbar and thoracic parts of the spine while standing, which can therefore be eliminated by providing toespace.
- Enhance the use of padded surfaces or anti-fatigue matting. Mats which are manufactured from plastic, rubber, or other resilient surfaces are useful tools to minimize discomfort and fatigue in the lower legs, feet, and back. Moreover,

mates can improve postural stability by providing adequate friction between the workers' feet and the work surface.

Administrative controls:

- Conduct periodic job/workstation inspections to identify areas where ergonomic-based risk factors may develop or are already present. Identified risk factors should be analyzed and eliminate before they contribute to the occurrence of undesirable consequences.
- Enhance job rotation in which workers are able to perform different tasks that do not require the same motions or use of body parts. With this approach, muscles and other body components can rest and heal while performing another job.
- The current pace of the rubber strip material requires the employee to perform rapid hand movements in order to direct it to the desired location within the bin. Therefore, it is recommended that management perform tests identify if a slower strip pace would reduce the employees MSD symptoms.
- Provide effective training programs that promote the employees' knowledge of what CTDs are and how to prevent them, and receive instruction on the proper use of tools/equipment.
- Ensure top management support and employee involvement. Clarify to workers how and why about standards and immediately praise compliance and address non-compliance. Moreover, encourage worker cooperation, especially during the decision-making process, because workers are close to the operation and can provide valuable information.
- Periodically administer employee symptom-surveys or/and medical-screening exams to uncover areas where musculoskeletal disorders may develop or are

already present. This approach also will identify such cases in the early stages before chronic illnesses may occur.

- After every change is made, continue to monitor the employee's ability to perform the task in order to identify any other productivity, quality or injury issues that may occur as a result of the process change. Moreover, care should be taken to identify if the implemented changes introduce new hazards or increase the risks of other tasks.
- Encourage the use of anthropometric data that allows workplace designers to accommodate a wide range of the population and thus promote the relationship between the workers and work environment. Such data will guide in identifying the appropriate adjustments and thus reduce or eliminate the opportunity for musculoskeletal disorders to develop among workers. Moreover, optimizing the relationship between workers and the work environment will allow the individuals to perform the job more effectively and efficiently.

Areas of Further Research

Further research is needed to help Company XYZ minimize additional risks that currently exist within the organization's processes in regard to the wig-wag operation:

- Conduct in-depth loss analysis to quantify the time lost from work, cases of modified duty, or changed jobs and to identify the costs of injuries and/or illnesses related to the wig-wag operation.
- Follow up with workers and perform medical-screening exams by trained personnel to identify the number of wig-wag operators experiencing CTDs, especially in the upper extremities.

- Expand the scope of research to analyze the non-ergonomic-based risk factors or physical hazards, such as machine guarding, which may be present for workers using the wig-wag machine and possess great potential to cause injuries or illnesses.
- The focus of this study's anthropometric analysis was narrow and specific to the wig-wag machine and its processes, and therefore management should expand the scope of the analysis to include other factory workstations and their demands.
- Investigate how strenuous work-demands on the aging workforce may significantly contribute to or elevate the risk of work-related musculoskeletal disorders.
- Perform a cost-benefit analysis to identify the most feasible interventions with regard to the engineering and/or the administrative controls which would reduce risk to an acceptable level and provide the company benefits within an acceptable payback period of time.
- Research other techniques or procedures that other companies in the rubber industry have utilized for similar operations.

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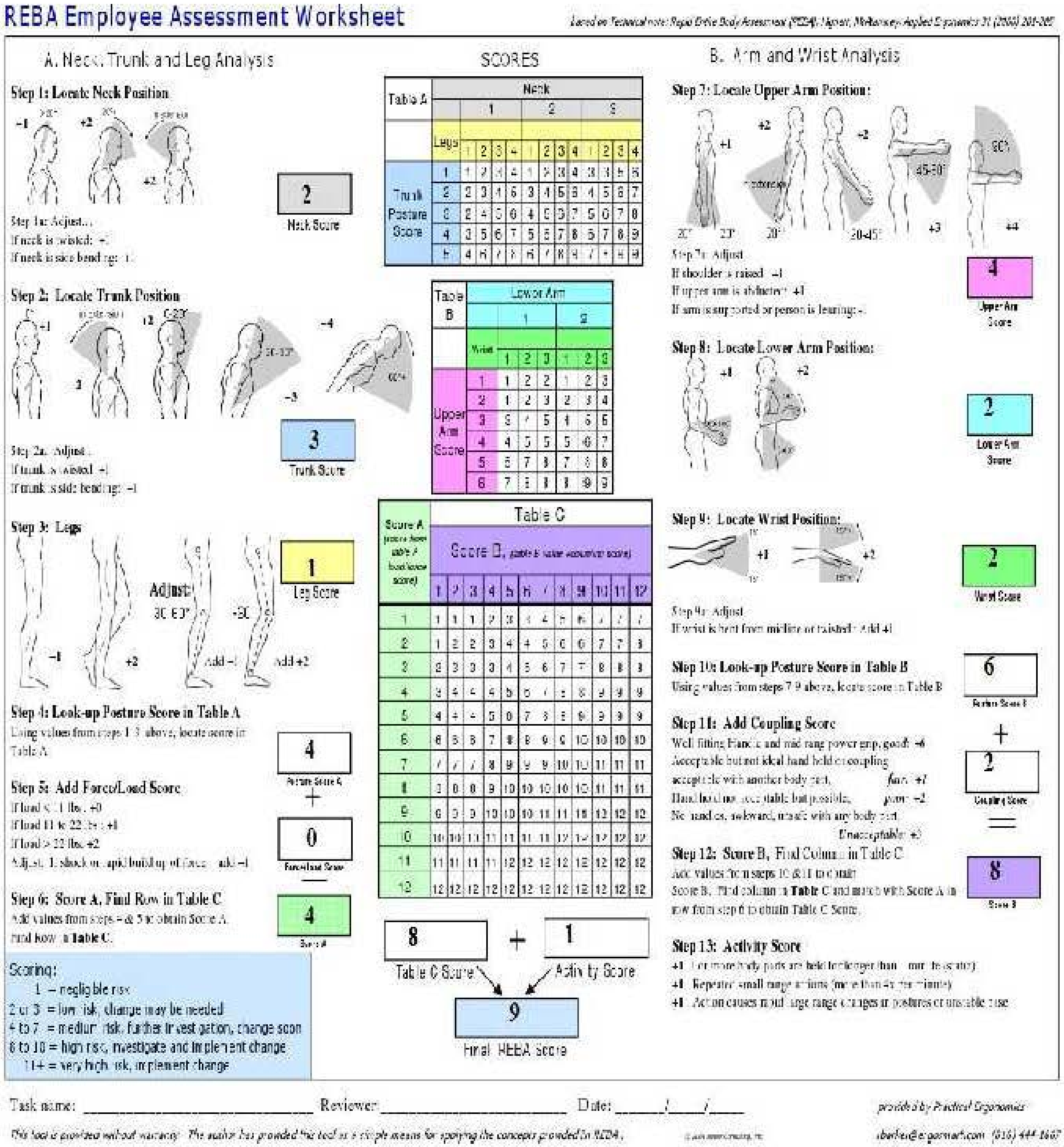
Appendix A: Rapid Entire Body Assessment (REBA)



REBA Employee Assessment Worksheet

Based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Neck Score: 2

Step 2: Locate Trunk Position

Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score: 3

Step 3: Legs

Adjust: 30-60°: Add +1; >60°: Add +2

Leg Score: 1

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above, locate score in Table A.

Posture Score A: 4

Step 5: Add Force/Load Score
If load < 11 lbs.: +0
If load 11 to 22 lbs.: +1
If load > 22 lbs.: +2
Adjust: If shock or rapid build up of force: add +1

Force/Load Score: 0

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A: 4

Scoring:
1 = negligible risk
2 or 3 = low risk, change may be needed
4 to 7 = medium risk, further investigation, change soon
8 to 10 = high risk, investigate and implement change
11+ = very high risk, implement change

SCORES

Table A	Neck	1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	6	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B	Lower Arm	1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C

Score A (score from table A + load/force score)	Score B, (table B value + coupling score) 1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score: 8 + Activity Score: 1

Final REBA Score: 9

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score: 4

Step 8: Locate Lower Arm Position:

Lower Arm Score: 2

Step 9: Locate Wrist Position:

Step 9a: Adjust...
If wrist is bent from midline or twisted: Add +1

Wrist Score: 2

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B: 6

Step 11: Add Coupling Score
Well fitting Handle and mid range power grip, *good*: +0
Acceptable but not ideal hand hold or coupling acceptable with another body part, *fair*: +1
Hand hold not acceptable but possible, *poor*: +2
No handles, awkward, unsafe with any body part, *Unacceptable*: +3

Coupling Score: 2

Step 12: Score B, Find Column in Table C
Add values from steps 10 & 11 to obtain Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B: 8

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Task name: ______________ Reviewer: ______________ Date: ___/___/___

provided by Practical Ergonomics

This tool is provided without warranty. The author has provided this tool as a simple means for applying the concepts provided in REBA.

[illegible] (816) 444-1667

Appendix B: Ergonomic Task Analysis Worksheet

Ergonomics Task Analysis Worksheet

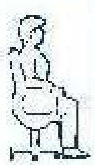
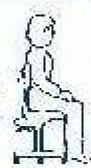
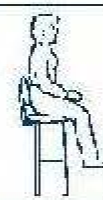
Directions: **The Ergonomics Task Analysis Worksheet** provides a method for identifying, evaluating, and eliminating/controlling ergonomic risk factors. Observe several task cycles prior to making notes or drawing conclusions. Score each risk factor (ideal, warning level, or take action) that most resembles the task you are analyzing. Once you have completed the worksheet, create an Action Plan (how to control or eliminate the risk factor), focusing on tasks from the "Take Action" column first. It is often helpful to videotape the job to facilitate a more detailed review and action plan.

Repetition

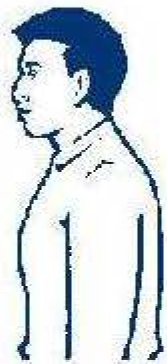
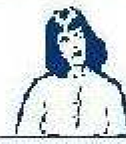
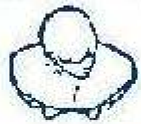
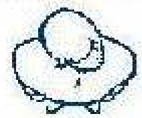
NIOSH defines a repetitive task as one with a task cycle time of less than 30 seconds or performed for prolonged periods, such as an 8-hour shift.

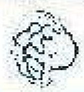
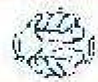
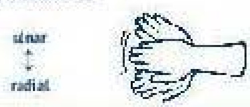
Ideal	Warning Level - Monitor	Take Action
1. No repetitive hand or arm motions	1A. Repetitive hand or arm motions with cycle times of 30-60 seconds	1B. Repetitive hand or arm motions with cycle times of less than 30 seconds

Posture

Ideal	Warning Level - Monitor	Take Action
Standing 2. Knees are straight, but not locked. Back is upright and straight. No twisting, reaching or bending (See reaching) 	**Standing** 2A. Knees partly bent. 	**Standing** 2B. Squatting > 3 hrs/day  2B. Kneeling > 3 hrs/day  2B. Using a foot pedal 
Sitting 3. Back and legs supported by comfortable chair. Feet are flat on floor or foot rest. 	**Sitting** 3A. Back is only partially supported or feet are not flat. 	**Sitting** 3B. Little support for legs and back. Feet do not touch floor. 
Head/Neck 4. Head and neck are upright and straight 	**Head/Neck** 4A. Bent forward less than 20° 	**Head/Neck** 4A. Bent forward more than 20° > 3 hrs/day 

Posture (continued)

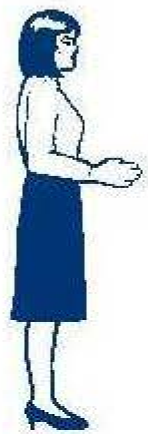
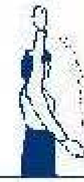
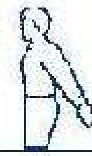
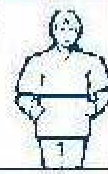
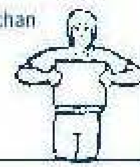
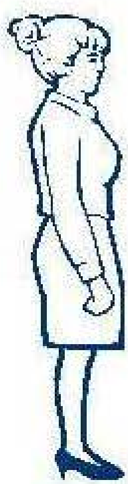
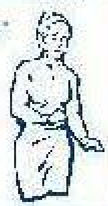
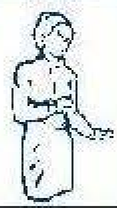
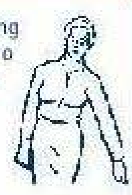
Ideal	Warning Level - Monitor	Take Action
Head/Neck 4. Head and neck are upright and straight 	**Head/Neck** 4B. Bent back less than 10˚ 	**Head/Neck** 4B. Bent back more than 10˚ 
	4C. Bent sideways less than 20˚ 	4C. Bent sideways more than 20˚ 
	4D. Twisting neck less than 20˚ 	4D. Twisting neck more than 20˚ 

Ideal	Warning Level - Monitor	Take Action
Hands 5. Palms are vertical (handshake position) 	**Hands** 5A. Hands rotate less than 20˚ 	**Hands** 5A. Hands rotate more than 20˚ 
Wrists 6. Wrists are straight 	**Wrists** 6A. Wrists are bent between 5 and 30 times per minute and bent less than 20˚ 	**Wrists** 6A. Wrists are bent more than 30 times per minute or bent more than 20˚ 
	6B. Wrists move sideways between 5 and 30 times per minute and less than 20˚ 	6B. Wrists move sideways more than 30 times per minute or more than 20˚ 

Vibration (Check with tool manufacturer for recommendations or warnings)

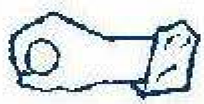
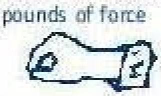
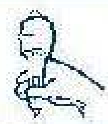
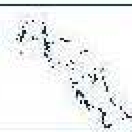
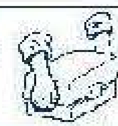
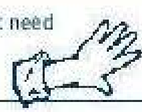
Ideal	Warning Level - Monitor	Take Action
7. No hand or arm vibration	7A. Occasional hand or arm vibration	7B. Constant hand or arm vibration
8. No whole body vibration	8A. Occasional whole body vibration	8B. Constant whole body vibration

Reach/Proper Height

Ideal	Warning Level - Monitor	Take Action
9. Work should be performed at 90˚ or slightly above or below elbow level 	9A. Arms forward up to 45˚ or frequently maintained outside of the ideal position > 4 hrs/day 	9A. Arms forward more than 45˚ or constantly maintained outside of the ideal position > 3 hrs/day 
	9B. Arms back up to 20˚ and no more than 2-4 times per minute > 4 hrs/day 	9B. Arms back more than 20˚ or more than 4 times per minute > 3 hrs/day 
	9C. Elbows bent up to 25% above or below the ideal position > 4 hrs/day 	9C. Elbows bent more than 25% above or below the ideal position > 3 hrs/day 
	9D. Elbows up to 45˚ away from body > 4 hrs/day 	9D. Elbows more than 45˚ away from body > 3 hrs/day 
10. No twisting, reaching or bending 	10A. Twisting up to 45˚ or frequent twisting (2-4 times per minute) 	10A. Twisting more than 45˚ or highly repetitive twisting (more than 4 times per minute) 
	10B. Bending/reaching forward up to 45˚, frequent bending (2-4 times per minute) or > 30% more than 4 hours per day without support 	10B. Bending/reaching forward more than 45˚, highly repetitive bending (more than 4 times per minute) or more than 2 hours per day without support 
	10C. Bending/reaching to the side up to 20˚ or frequent bending (2-4 times per minute) 	10C. Bending/reaching to the side more than 20˚ or highly repetitive bending to the side (more than 4 times per minute) 

Force

Force is the amount of physical effort required to do a task or maintain control of the tools or equipment. Effort depends on the weight of the object, type of grip, object dimensions, type of activity, slipperiness of the object and duration of the task.

Ideal	Warning Level - Monitor	Take Action
11. Objects lifted by hand weigh less than 1 pound	11A. Objects lifted by hand weigh less than 1 pound and frequent lifting (no more than 20 times an hour)	11B. Objects lifted by hand weigh more than 1 pound or highly repetitive lifting (more than 20 times an hour)
12. Objects lifted by the back weigh less than 5 pounds	12A. Objects lifted by the back weigh between 5 and 25 pounds or frequent lifting (no more than 20 times/hour)	12B. Objects lifted by the back weigh more than 25 pounds or highly repetitive lifting (more than 20 times/hour)
Duration 13. No pinch grip used. Fingers and thumb comfortably fit around tool or object 	**Duration** 13A. Moderate pinch grip or pinch grip with less than 2 pounds of force 	**Duration** 13A. Severe pinch grip or pinch grip used with greater than 2 pounds of force 
	13B. Grip is slightly too wide 	13B. Grip is extremely wide 
14. Power grip used with little to no force.	14A. Power grip used with less than 10 pounds of force. Forearm rotation force is less than 5 pounds	14B. Power grip used with more than 10 pounds of force. Forearm rotation force is more than 5 pounds
15. Entire hand controls trigger 	15A. Thumb activated control 	15B. Finger(s) activated control 
16. Tools or objects have handles that are rounded	16A. Awkward handles	16B. Handles, tools or objects that concentrate force or have no handles
	16A. Tools with awkward handles 	16B. Handles that concentrate force 
	Choose One	
	16A. Objects with awkward handles 	16B. Objects with no handles 
Slipperiness 17. Gloves do not need to be worn at any time 	**Slipperiness** 17A. Gloves are needed but fit well 	**Slipperiness** 17B. Gloves are needed but fit poorly 

Static Loading and Fatigue

Static loading refers to staying in the same position for prolonged periods. Tasks that use the same muscles or motions for long durations (6 seconds or more at one time) and repetitively (more than 50% repetition) increase the likelihood of fatigue.

Ideal	Warning Level - Monitor	Take Action
Duration 18. Constant position, tool or object is held less than 6 seconds	**Duration** 18A. Constant position, tool or object is held 6 to 10 seconds	**Duration** 18B. Constant position, tool or object is held more than 10 seconds
Repetition 19. Less than 25% of the task is repetitive	**Repetition** 19A. 25% to 50% of the task is repetitive	**Repetition** 19B. More than 50% of the task is repetitive

Pressure/Contact Stress/Repeated Impacts

Refers to pressure or contact from tools or equipment handles with narrow width that create local pressure. It also applies to sharp corners of desks or counter tops. Impact refers to the use of hands, knees, foot, etc. as a hammer. *(Related to Force Conditions in item 16.)*

Ideal	Warning Level - Monitor	Take Action
20. No contact or impact stress: tools, objects, or workstation do not press against hands or body	20A. Occasional and minimal pressure or impact on hands or body. Hand, knee or other body part used as hammer less than 2 hours/day	20B. Constant pressure or impact on hands or body. Hand, knee or other body part used as hammer more than 2 hours/day

Lifting and Materials Handling

Ideal	Warning Level - Monitor	Take Action
21. No lifting or lowering of materials (see also Force for weights of objects handled)	21A. Occasional lifting and/or lowering (no more than 20 times per hour)	21B. Constant lifting and/or lowering (more than 20 times per hour)
Push/Pull 22. No pushing or pulling of carts or materials	**Push/Pull** 22A. Pushing or pulling 10-50 carts per shift	**Push/Pull** 22B. Pushing or pulling more than 50 carts per shift
23. Slight force is required to push or pull carts or materials. Pushing is preferred over pulling objects.	23A. Moderate force is required to push or pull carts or materials.	23B. High force is required to push or pull materials.

Environment

Ideal	Warning Level - Monitor	Take Action
Work Pace 24. Worker has adequate control over work pace.	**Work Pace** 24A. Worker has some control over work pace.	**Work Pace** 24B. Worker has no control over work pace.
Lighting 25. The lighting is adequate for the task.	**Lighting** 25A. The lighting is slightly too bright or too dark for the task.	**Lighting** 25B. The lighting is significantly too bright or too dark for the task.
Temperature 26. The temperature is comfortable.	**Temperature** 26A. The temperature is slightly too cold or too hot.	**Temperature** 26B. The temperature is significantly too cold or too hot.
Noise 27. The work area is quiet.	**Noise** 27A. The work area is slightly noisy.	**Noise** 27B. The work area is significantly noisy (too noisy to carry on a conversation).
Floor Surface 28. The flooring provides good traction. 29. The flooring is sufficiently padded to relieve stress on back and legs. 30. Floor mats are provided to relieve stress on back and legs. Employee can alternate between sitting and standing.	**Floor Surface** 28A. The flooring is slightly slippery. 29A. The flooring contributes slight stress to the back and legs. 30A. Standing 0-50% of time without floor mats or other means to relieve stress on back and legs.	**Floor Surface** 28B. The flooring is moderately to extremely slippery. 29B. The flooring contributes moderate to extreme stress to the back and legs. 30B. Standing more than 50% of time without floor mats or other means to relieve stress on back and legs.

Comments: ______________________________

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Note: The levels provided above are standard practices which have been accepted or established by NIOSH, OSHA, ANSII and other related organizations.

Summary Worksheet

Date ________________

Condition	Ideal	Warning Level	Take Action
Repetition			
1. No repetitive hand or arm motions. (*Monitor* if repetitive cycle every 30-60 seconds; *take action* if repetitive cycle of less than 30 seconds.)	1	1A	1B
Posture			
2. Standing, with knees straight but not locked. (*Monitor* if standing with knees partially bent; *take action* if using a foot pedal or squatting or kneeling more than 3 hours/day.)	2	2A	2B
3. Sitting, back and legs comfortably supported, feet flat on floor/floor rest. (*Monitor* if back partially supported or feet not flat on floor; *take action* if little support for back and legs, feet not touching floor.)	3	3A	3B
4. Head and neck are upright and straight. (*Monitor* if head and neck are bent forward < 20°; *take action* if >20° >3 hours/day.)	4	4A	4A
Head and neck are bent back. (*Monitor* if < 10°; *take action* if >10°.)	4	4B	4B
Head and neck are bent sideways. (*Monitor* if < 20°; *take action* if >20°.)	4	4C	4C
Head and neck are twisting. (*Monitor* if < 20°; *take action* if >20°.)	4	4D	4D
5. Hands (palms) are vertical. (*Monitor* if hands rotate < 20°; *take action* if hands rotate >20°.)	5	5A	5B
6. Wrists are straight. (*Monitor* if wrists are bent, extension/flexion, < 20° for 5-30 times/minute; *take action* if bent >20° or >30 times/minute.)	6	6A	6A
Wrists move sideways, ulnar/radial. (*Monitor* if < 20° and 5-30 times/minute; *take action* if bent >20° or >30 times/minute.)	6	6B	6B
Vibration			
7. No hand or arm vibration. (*Monitor* if occasional; *take action* if constant.)	7	7A	7B
8. No whole body vibration. (*Monitor* if occasional; *take action* if constant.)	8	8A	8B
Reach			
9. Arms positioned at elbow level. (*Monitor* if up to 45° or frequently out of ideal position for more than 4 hours/day; *take action* if arms are forward >45° or constantly out of ideal position >3 hours/day.)	9	9A	9A
Arms back. (*Monitor* if arms back up to 20° between 2-4 times/minute for more than 4 hours/day; *take action* if arms back >20° or >4 times/minute for more than 3 hours/day.)	9	9B	9B
Elbows bent upward. (*Monitor* if elbows bent up to 25% above or below ideal position >4 hours/day; *take action* if bent upward >25% above or below ideal position >3 hours/day.)	9	9C	9C
Elbows away from body. (*Monitor* if elbows are up to 45° away from body >4 hours/day; *take action* if elbows are >45° away from body >3 hours/day.)	9	9D	9D
10. No twisting, reaching or bending, twisting/repetitive. (*Monitor* if twisting up to 45° or 2-4 times/minute; *take action* if >45° or >4 times/minute.)	10	10A	10A
Reaching/bending forward. (*Monitor* if bending/reaching forward up to 45° or 2-4 times/minute or >30° for >4 hrs/day w/out support; *take action* if >45° or >4 times/minute or >2 hrs/day w/out support.)	10	10B	10B
Reaching/bending to the side. (*Monitor* if up to 20° or 2-4 times/minute; *take action* if >20° or >4 times/minute.)	10	10C	10C
Force			
11. Objects lifted by hand weigh less than one pound. (*Monitor* if objects weighing < 1 lb. are lifted up to 20 times/hour; *take action* if objects weigh >1 lb. or lifting occurs >20 times/hour.)	11	11A	11B
12. Objects lifted by the back weigh less than 5 pounds. (*Monitor* if objects weigh 5-25 lbs. or lifting occurs up to 20 times/hour; *take action* if objects weigh >25 lbs. or lifting occurs >20 times/hour.)	12	12A	12B
13. No pinch grip used. (*Monitor* use of pinch grip with < 2 lbs. of force; *take action* if pinch grip with >2 lbs. of force is used.)	13	13A	13A
Wide pinch grip used. (*Monitor* if slightly too wide; *take action* if extremely wide.)	13	13B	13B
14. Power grip used with no force. (*Monitor* if power grip with < 10 lbs. force is used and forearm rotation force is < 5lbs.; *take action* if power grip with >10 lbs. force is used and forearm rotation force is >5 lbs.)	14	14A	14B
15. Entire hand controls trigger. (*Monitor* if thumb controls; *take action* if finger[s] control.)	15	15A	15B
16. Tools or objects have rounded, padded handles. (*Monitor* if handles are awkward; *take action* if there are no handles or handles concentrate force.)	16	16A	16B
17. Gloves do not need to be worn at any time. (*Monitor* if gloves are needed but fit well; *take action* if gloves fit poorly.)	17	17A	17B
Static Loading and Fatigue			
18. Constant position, tool or object is held less than 6 seconds. (*Monitor* if held between 6-10 seconds; *take action* if held >10 seconds.)	18	18A	18B
19. Less than 25% of the task is repetitive. (*Monitor* if 25-50% repetitive; *take action* if >50% repetitive.)	19	19A	19B
Pressure/Contact Stress/Repeated Impacts			
20. No contact/impact stress (*Monitor* if occasional pressure or body part is used as hammer < 2 hours/day; *take action* if constant pressure or body part is used as hammer >2 hours/day.)	20	20A	20B

Summary Worksheet

Date ______________

Condition	Ideal	Warning Level	Take Action
Lifting and Materials Handling			
21. No lifting or lowering of materials. (*Monitor* if occasional and/or no more than 20 times/hour; *take action* if constant and/or greater than 20 times/hour.	21	21A	21B
22. No pushing or pulling of materials. (*Monitor* if pushing/pulling 10-50 carts/shift; *take action* if pushing/pulling more than 50 carts/shift.)	22	22A	22B
23. Slight force is required to push or pull materials. (*Monitor* if moderate force is required; *take action* if high force is required.)	23	23A	23B
Environment			
24. Worker has adequate control over workplace. (*Monitor* if worker has some control; *take action* if worker has no control.)	24	24A	24B
25. Lighting is adequate for the task. (*Monitor* if slightly too dark or bright; *take action* if significantly too dark or bright.)	25	25A	25B
26. Temperature is comfortable. (*Monitor* if slightly too cold or hot; *take action* if significantly too cold or hot.)	26	26A	26B
27. Work area is quiet. (*Monitor* if slightly too noisy; *take action* if significantly too noisy.)	27	27A	27B
28. Flooring provides good traction. (*Monitor* if flooring is slightly slippery; *take action* if moderately to extremely slippery.)	28	28A	28B
29. Flooring is sufficiently padded to relieve stress on back and legs. (*Monitor* if slight stress to back and legs; *take action* if moderately to extreme stress.)	29	29A	29B
30. Floor mats are provided. Employee can alternate between sitting and standing. (*Monitor* if employee is standing up to 50% of shift without floor mats or other stress relief for back and legs; *take action* if standing >50% of shift without floor mats or other relief for back and legs.	30	30A	30B

Action Plan

Today's date: ________________ Date Solution to be Completed ______________________________

Location/Department: ____

Job/Task Title: ____

Evaluator: ____

Describe MSD in previous 24 months: ______________________________________

____

Task: ____

Summary of Problem: ____

____

Alternative Solution and Costs: ____

____

Recommended Solution: 1) Engineering _____________________________________

____

2) Administrative: ____

____

3) Use of personal protective equipment ____________________________________

____

Date Solution Actually Completed: ______________________ Actual Cost: ________________

GREAT AMERICAN INSURANCE GROUP

Appendix C: Pain/Discomfort Symptom Survey

Date ___ / ___ / ___

Work Location ______________________ Job _________________________

Phone ____________ Work Hours __________ Supervisor ________________

Time on THIS job:

❑ Less than 3 months ❑ 3 months to 1 year

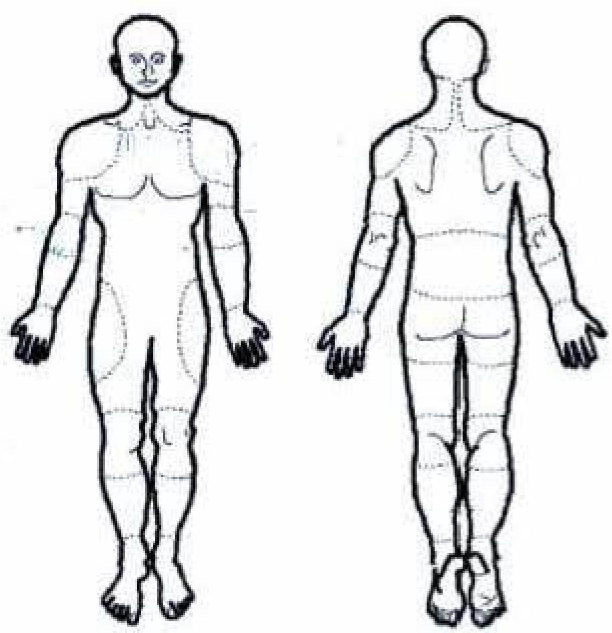
❑ Greater than 1 year to 5 years ❑ Greater than 5 years to 10 years

❑ Greater than 10 years

Have you had any pain or discomfort during the last year?

❑ Yes ❑ No (If NO, skip to next page)

If YES, please shade in the area of the drawings below which bothers you the MOST:



Symptom survey

Name: ________________________________

1. Check area where symptoms are present:
   - ❑ Neck ❑ Elbow/Forearm ❑ Upper Back ❑ Thigh/Knee ❑ Fingers
   - ❑ Shoulder ❑ Hand/Wrist ❑ Low Back ❑ Lower Leg ❑ Ankle/Foot

2. Please put a check by the word(s) that best describe your symptoms:
   - ❑ Aching/Cramp ❑ Numbness/Tingling ❑ Stiffness
   - ❑ Burning ❑ Pain ❑ Weakness
   - ❑ Loss of Color ❑ Swelling ❑ Other

3. When did you first notice the problem? _______ number of months -or- ________ years ago

4. How long does each episode last? (please check)
   - ❑ less than 1 hour ❑ 24 hours to 1 week ❑ 1 month to 6 months
   - ❑ 1 hour to 24 hours ❑ 1 week to 1 month ❑ more than 6 months

5. How many separate episodes have you had in the last year? ________________________

6. What do you think caused the problem? ____

   ____

7. Have you had the problem in the last 7 days? ❑ Yes ❑ No

8. How would you rate this problem? Mark an X on the line.

   RIGHT NOW: **None** ________________________________ **Unbearable**

   AT ITS WORSE: **None** ________________________________ **Unbearable**

9. Have you had medical treatment for this problem? ❑ Yes ❑ No

   If yes, what was the diagnosis? ____

10. How much time have you lost from work in the last year because of this problem? _____ days

11. How many days in the last year were you on modified duty because of this problem? _____ days

12. Have you changed jobs because of this problem? ❑ Yes ❑ No

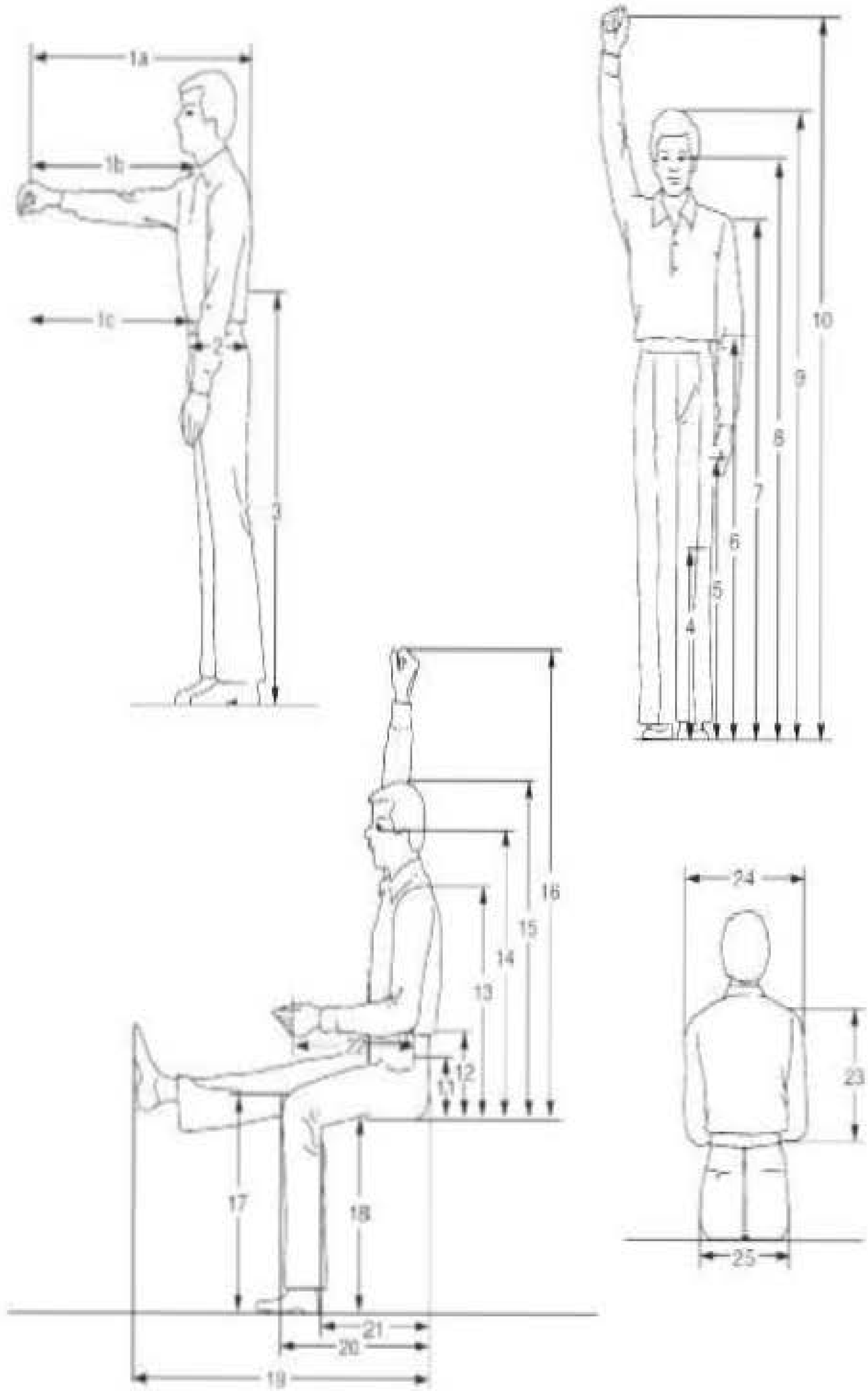
Appendix D: Anthropometric Table of U.S Anthropometric Data, Inches (Champney 1979; Muller-Borer 1981; NASA 1978)

U.S. Anthropometric Data, Inches (Champney 1979; Muller-Borer 1981; NASA 1978)*

The data here are the same as in Table 1.5, but they are expressed in inches.

Measurement	Males		Females		Population Percentiles, 50/50 Males/Females		
	50th percentile	± 1 S.D	50th percentile	± 1 S.D	5th	50th	95th
STANDING							
1. Forward functional reach							
a. Includes body depth at shoulder	32.5 (31.2)	1.9 (2.2)	29.2 (28.1)	1.5 (1.7)	27.2 (25.7)	30.7 (29.5)	35.0 (34.1)
b. Acromial process to functional pinch	26.9	1.7	24.6	1.3	22.6	25.6	29.3
c. Abdominal extension to functional pinch**	(24.4)	(3.5)	(23.8)	(2.6)	(19.1)	(24.1)	(29.3)
2. Abdominal extension depth	9.1	0.8	8.2	0.8	7.1	8.7	10.2
3. Waist height	41.9 (41.3)	2.1 (2.1)	40.0 (38.8)	2.0 (2.2)	37.4 (35.8)	40.9 (39.9)	44.7 (44.5)
4. Tibial height	17.9	1.1	16.5	0.9	15.3	17.2	19.4
5. Knuckle height	29.7	1.6	28.0	1.6	25.9	28.8	31.9
6. Elbow height	43.5 (45.1)	1.8 (2.5)	40.4 (42.2)	1.4 (2.7)	38.0 (38.5)	42.0 (43.6)	45.8 (48.6)
7. Shoulder height	56.6 (57.6)	2.4 (3.1)	51.9 (56.3)	2.7 (2.6)	48.4 (49.8)	54.4 (55.3)	59.7 (61.6)
8. Eye height	64.7	2.4	59.6	2.2	56.8	62.1	67.8
9. Stature	68.7 (69.9)	2.6 (2.6)	63.8 (64.8)	2.4 (2.8)	60.8 (61.1)	66.2 (67.1)	72.0 (74.3)
10. Functional overhead reach	82.5	3.3	78.4	3.4	74.0	80.5	86.9

Measurement	Males		Females		Population Percentiles, 50/50 Males/Females		
	50th percentile	± 1 S.D	50th percentile	± 1 S.D	5th	50th	95th
FOOT							
26. Foot length	10.5	0.5	9.5	0.4	8.9	10.0	11.2
27. Foot breadth	3.9	0.2	3.5	0.2	3.2	3.7	4.2
HAND							
28. Hand thickness, metacarpal III	1.3	0.1	1.1	0.1	1.0	1.2	1.4
29. Hand length	7.5	0.4	7.2	0.4	6.7	7.4	8.0
30. Digit two length	3.0	0.3	2.7	0.3	2.3	2.8	3.3
31. Hand breath	3.4	0.2	3.0	0.2	2.8	3.2	3.6
32. Digit one length	5.0	0.4	4.4	0.4	3.8	4.7	5.6
33. Breadth of digit one interphalangeal joint	0.9	0.05	0.8	0.05	0.7	0.8	1.0
34. Breadth of digit three interphalangeal joint	0.7	0.05	0.6	0.04	0.6	0.7	0.8
35. Grip breadth, inside diameter	1.9	0.2	1.7	0.1	1.5	1.8	2.2
36. Hand spread, digit one to digit two, first phalangeal joint	4.9	0.9	3.9	0.7	3.0	4.3	6.1
37. Hand spread, digit one to digit two, second phalangeal joint	4.1	0.7	3.2	0.7	2.3	3.6	5.0
HEAD							
38. Head breadth	6.0	0.2	5.7	0.2	5.4	5.9	6.3
39. Interpupillary breadth	2.4	0.2	2.3	0.2	2.1	2.4	2.6
40. Biocular breadth	3.6	0.2	3.6	0.2	3.3	3.6	3.9
OTHER MEASUREMENTS							
41. Flexion-extension, range of motion of wrist, in degrees	134	19	141	15	108	138	166
42. Ulnar-radial range of motion of wrist, in degrees	60	13	67	14	41	63	87
43. Weight, in kilograms	183.4	33.2	146.3	30.7	105.3	164.1	226.8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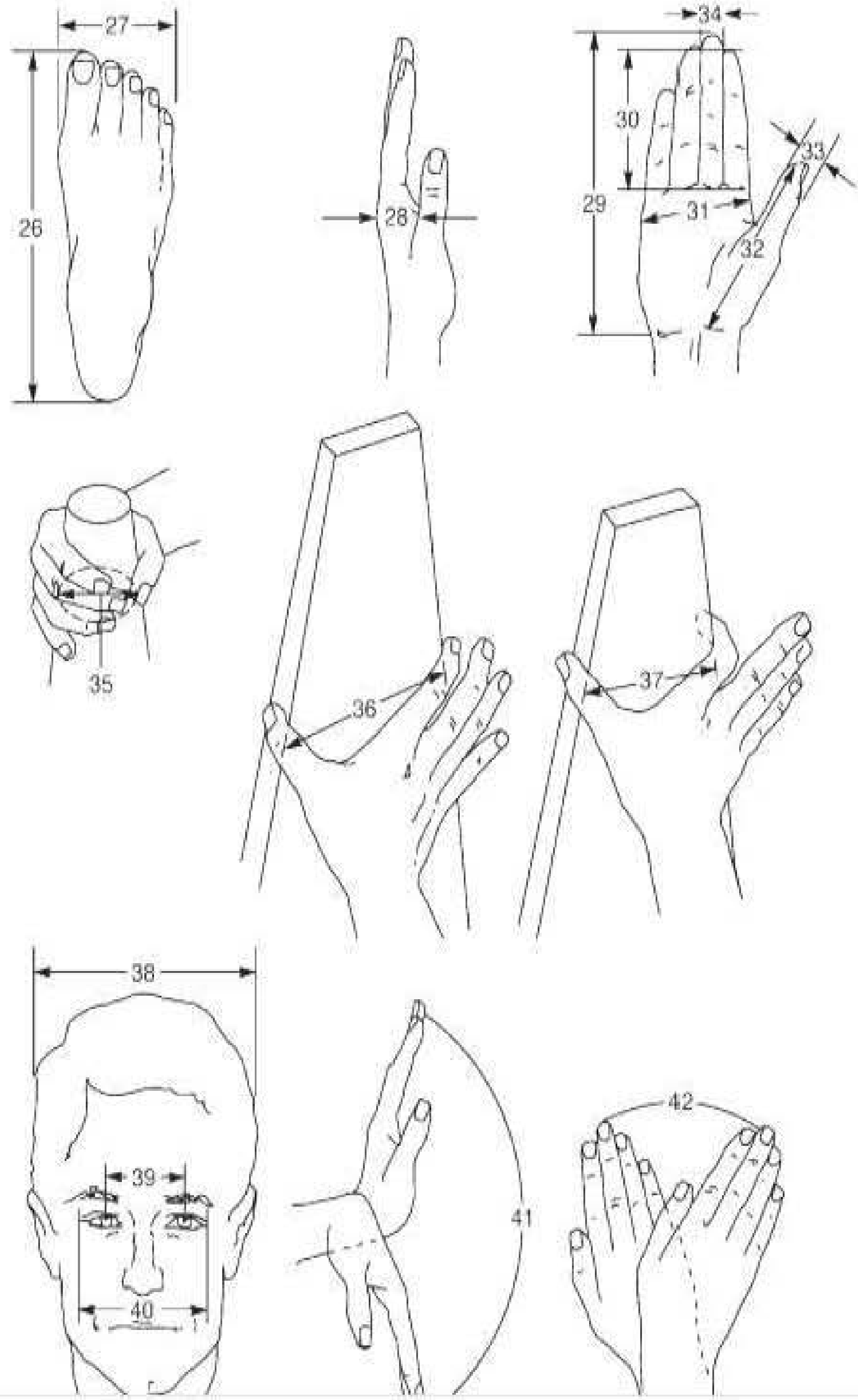
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Appendix E: Consent to Participate In UW-Stout Approved Research

Consent to Participate In UW-Stout Approved Research

Title: An ergonomic assessment of the use of the wig-wag machine at a ruber factory

Investigator:
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Research Sponsor:
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Description:

The purpose of this study is to analyze the ergonomic-based risk factors which are present for workers using the wig-wag machine at the Company XYZ. The current process of the wig-wag-machine exposes the operators to ergonomic risk factors such as repetitive motion, awkward posture, and excessive exposure time which possess a significant contribution to cause a work-related musculoskeletal disorder injury (MSDs). In this study, a variety of ergonomic risk assessment tools will be utilized to aid in the identification of such risk factors associated with the current process of the machine which include Rapid Entire Body Assessment (REBA) assessment worksheet, an ergonomic task analysis worksheet, an employee symptom survey, and a review of available regulatory injury/illnesses records. This study attempts to identify the ergonomic stressors, assess their magnitude, and then provide recommendations to eliminate or to reduce the present risk to an acceptable level which ultimately will promote the employees' health and safety

Risks and Benefits:

Risks: This study attempts to evaluate the task. Thus, no forseeable risk will be introduced to the subjects. The only area of concern is that a participant may not feel confortable while being observed or recorded. If a participant does not prefer to be recorded through video or photography, then such will not take place. Harm or physical risk is unlikely to occur since the subjects will not be asked to perform any task beyond the required job that they perform during a normal day.

Benefits: This analysis will assist in identifying the ergonomic-related risk factors associated with the task which place the workers at the risk of developing MSDs. Once the analysis is completed, recommendations will be provided in order to eliminate or reduce the level of risk. Doing so will not only promote the safety and health aspects of the workers, but will also help the company to reduce the burdens caused by the associated stressors including the financial aspects.

Time Commitment and Payment:

Participating in this study is voluntary. The subjects would be observed while they perform their respective tasks as they would during a normal day. Thus, there is no foreseeable time commitment in this study and no compensation or payments would be offered.

Confidentiality:

You will be observed while performing in the wig-wag machine process and then will be asked to complete a symptom/discomfort survey. Video recording will be taken while you perform the respective job for the purpose of the analysis. You will not be asked to perform any task beyond the normal wig-wag process. Your name or any other peronal identifier information will not be included in any documents. We do not believe that you can be identified from any of this information. The video recording will not show any of the subject's faces, and no images from the video will be used in the report. All the obtained data and documents will be used only by the researcher for the purposes of this study.

Right to Withdraw:

Your participation in this study is entirely voluntary. You may choose not to participate without any adverse consequences to you. You have the right to stop the survey at any time. However, should you choose to participate and later wish to withdraw from the study, there is no way to identify your anonymous document after it has been turned into the investigator.

IRB Approval:

This study has been reviewed and approved by The University of Wisconsin-Stout's Institutional Review Board (IRB). The IRB has determined that this study meets the ethical obligations required by federal law and University policies. If you have questions or concerns regarding this study please contact the Investigator or Advisor. If you have any questions, concerns, or reports regarding your rights as a research subject, please contact the IRB Administrator.

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Statement of Consent:

By completing the following survey and allowing the video recording of the performance of your task, you agree to participate in the project entitled, (An ergonomic assessment of the use of the wig-wag machine at a rober factory)."

Signature and date ____________________