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**Abstract**

This study involved an analysis of multiple risk factors that wind turbine tower maintenance technicians are exposed to as a result of climbing ladders. A daily part of a wind turbine tower maintenance technician’s occupation involves extensive climbing of vertical wind turbine ladders which are suspected to result in the development of musculoskeletal disorders. The study involved administering wind tower technicians to an online survey of 112 questions which were written specifically to identify the risk factors, musculoskeletal disorder symptoms and working conditions which are associated with maintaining wind turbines. The study included an analysis of 30 online survey responses as well as video recordings of technicians performing wind turbine ladder climbing activities. The Great American Insurance Company Ergonomics Task Analysis Worksheet was also utilized to augment the ergonomic analysis of the video recorded wind turbine ladder climbing activities. The results of the online survey indicated that over 80% of survey respondents reported experiencing musculoskeletal disorder symptoms due to wind turbine ladder climbing activities. A task analysis of the wind turbine ladder climbing activity indicates that it is physically stressful due to the associated technicians’ routine exposure to repetitive movement, unfavorable posture, forceful exertion, temperature extreme and duration-related risk factors.
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Chapter I: Introduction

Current data from the Occupational Outlook Handbook from the Bureau of Labor Statistics, states that there are approximately 5,800 wind turbine technician jobs in the United States (2018). If the trend towards building additional wind turbines in the United States continues on its current path, the number of individuals working in this occupational field is expected to nearly double in size to an estimated 11,400 technician-oriented jobs by the year 2026 (Bureau of Labor Statistics, 2018). Whether the wind turbine technician profession doubles in size during the coming eight years or not, it is likely that occupational safety will be an important consideration for each individual who is employed as a wind turbine technician.

Ergonomics exists as one of the fundamental subject areas within the discipline of industrial hygiene. In fact, a 2015 article for the Harvard T.H. Chan School of Public Health, lists ergonomics at the top of the “key components of industrial hygiene” (Hersh, 2015, para. 8). “Industrial hygienists analyze, identify, and measure workplace hazards or stresses that can cause sickness, impaired health, or significant discomfort in workers through chemical, physical, ergonomic, or biological exposures” (OSHA Office of Training and Education, 1998, p. 2). Accordingly, it could be surmised that not only is ergonomics one of the primary and fundamental subject areas within the discipline of industrial hygiene, but that the application of ergonomic principles and the recognition of ergonomic-based risk exposures is likewise one of the elemental aspects of a viable occupational health and safety program. In addition to influencing decision-making connected to the design of tasks, processes, and work environments, ideally, ergonomics functions as a basic underlying principle consistent with the functional maintenance of employee health and operational longevity. Ergonomic research helps to not only identify the specific risk factors which lead to musculoskeletal disorders and injuries, but
also helps to remove the risk factors through redesign of the work and thus prevent injuries and musculoskeletal disorders from occurring in the workplace (Tayyari & Smith, 1997, p. 1).

Regrettably, specific data related to the occupational injuries and musculoskeletal disorders which are incurred by wind turbine technicians is not currently available from official government sources such as the Bureau of Labor Statistics (BLS). However, the musculoskeletal disorder and injury data that is readily available from the BLS for other occupations with similar types of manual labor tasks may be of interest in relation to an ergonomic study of wind turbine technicians. Not only may this type of data for other occupations be noteworthy, it may also support an extrapolation or inference leading to an enhanced understanding of the potential for occupational injuries and musculoskeletal disorders that could be incurred by wind turbine technicians. This subject matter is revisited in the Literature Review in Chapter II.

Company XYZ designs and manufactures equipment for electrical power generating wind turbine towers. The equipment currently manufactured by Company XYZ consists of cable-driven wind tower elevators, rack-and-pinion wind tower elevators, ladders, climb assist devices and fall protection devices. These types of equipment are utilized to assist workers and wind turbine technicians in ascending to the turbine area at the top of the towers in order to perform maintenance activities. After the technicians have performed their maintenance-related activities, the same equipment is utilized to descend to the base of the tower.

The platform at the top of a wind turbine tower is called the nacelle and it is within this area that maintenance work typically takes place. It is generally necessary for wind tower workers and service technicians to reach the nacelle in order to service the various moving parts and functional components of the turbine. In this way, the wind tower technician actually has between two to three separate tasks. The first task involves performing any necessary work on
components which are located at the ground level. The second task involves donning fall protection equipment and safely as well as efficiently ascending the structure to the nacelle. Ascending a ladder alone could be a strenuous job entirely in and of itself, especially considering the typical height of wind turbine ladders and the potentially harsh outdoor workplace environmental conditions of wind turbine towers. After reaching the nacelle, the wind turbine technician is then able to perform various maintenance duties. Finally, the last job of the technician is to carefully descend from the nacelle back to the ground level. Wind tower technicians typically work in groups of two or three. It is not certain that they will always be in constant contact with one-another or maintain constant visual sight of one another, but ideally, no individual will be working completely alone or left completely unaccompanied or out of radio/cellphone contact for a very long stretch of time during the work-shift. This practice of maintaining a group or team approach is an appropriate and natural response to the inherently hazardous nature of the job-site and working conditions which are commonly located in remote areas potentially quite far from any outside emergency assistance and subject to intrinsically strong winds or extreme weather conditions.

Historically, the individuals responsible for servicing and repairing the wind turbine and constituent components must manually climb ladders which measured approximately 80 to 100-meters in height (roughly 262 ft. to 328 ft.) to reach the internal turbine area at the top of the nacelle. In approximately 2010, climb assist devices and wind tower elevators (service lifts) were brought into the industry to be used in conjunction with the ladders. Climb assist devices attach a wire rope to a worker’s fall protection harness and use a motorized winching system to gently help pull the worker up as he/she manually climbs the ladder. This assistive device uses a cable which is altogether separate from the fall protection cable or rail-based ladder safety
systems which run up the center of the ladder (and to which the climber is connected through an apparatus attached to a d-ring located on the chest strap of their fall-protection harness). Climb assist devices do not totally perform the work for the user and thus only relieve a certain amount of the physical stress as the technician ascends or descends the ladder.

Another worker lifting option includes the use of a service lift which is reminiscent of a stripped-down industrial utilitarian hotel elevator. Wind turbine service lifts come in several different shapes, sizes, and speeds, but generally consist of a metallic cage that can typically hold one to two personnel as well as certain tools or equipment. The cage of the service lift is attached to a robust set of steel wire ropes that stretch from the top section of the tower to nearly the bottom (lifts do not always start at the ground level). An electric motor inside the lift cage is attached to the wire ropes and it propels the lift at the press of a button. When the button is released, the motor disengages and acts as a braking system to stop the lifting process. In the unlikely event of an adverse condition or situation related to the motor or the wire ropes, a fail-safe emergency braking system automatically activates to stop the lift and hold it in place. In the event that an electric motor in a service lift were to malfunction, this lifting device is always located within an arm’s reach of the tower ladder so that an individual could use a fall protection harness and lanyards to reach out of the service lift and securely attach themselves to the ladder before exiting the lift onto the ladder. Once the occupants safely exit the lift and have attached themselves to the ladder, they could then proceed with ascending or descending the tower, whichever the situation may dictate. This system of integrating the service lifts with the ladders mandates that a ladder must be present in every wind turbine tower as an essential component of the tower infrastructure. On their own, ladders are by no means the most favorable, efficient, or risk-averse method of ascending and descending from wind turbine towers.
Wind turbine towers are getting taller. They are being built taller over time because of the naturally occurring phenomenon in which the wind provides more energy to be captured at higher turbine elevations and the generation of wind power is more profitable and efficient when the turbine towers are built taller (Lantz et al., 2019). This trend presents additional concerns when combined with the fact that over the last several years, the costs associated with inspecting, maintaining, and certifying wind turbine tower service lift elevators have increased, and because of these rising and continuing expenses, there is the potential that the organizations which own and operate the towers for the purpose of generating profitable electric power will decide to stop paying for inspection, maintenance, and certification of turbine tower service lift elevators in an attempt to cut costs and thus save money. This practice will likely change the way that wind turbine technicians perform their jobs by reverting back to the exclusive use of ladders as a labor-intensive means of ascending and descending the wind towers. This is an unfortunate trend because of the potential for decreased worker productivity as well as the inherent musculoskeletal stress which is placed on wind tower technicians and maintenance workers during the performance of their job duties. This trend potentially inhibits overall worker productivity by removing the most efficient means and best available technology for workers to efficiently access the top of the turbine tower and return safely to the ground when they are finished so that they can proceed to the next nearby wind turbine. Thus, the need for maintenance workers to frequently climb the internal ladders of power generating wind turbine towers throughout their daily work-shift is placing these employees at risk of experiencing upper as well as lower extremity musculoskeletal disorders.
Purpose of the Study

The purpose of this study is to identify the extent to which musculoskeletal disorders may occur among maintenance employees who are required to frequently climb wind power generation towers throughout their daily work-shift.

Goals of the Study

The goals of this study include:

1. Survey wind power generator tower employees to determine the extent that they are experiencing various musculoskeletal disorder symptoms.

2. Perform ergonomic assessments of wind power generator tower maintenance personnel ladder climbing activities in order to quantify the extent of force, posture, repetition, duration, and temperature-related risk factors to which employees are typically exposed.

3. Compare the quantified tower maintenance employee risk factors against commonly-used ergonomic risk assessment tools.

Background and Significance

The health and well-being of wind tower maintenance personnel is of interest to Company XYZ. In order to better understand this situation, the company needs to study the ergonomic and musculoskeletal impacts of climbing ladders on the human body. There are certain types of risks that the ladder climbing activities place on the respective electrical wind tower generation maintenance employees and their employers. In the case of the maintenance employees, the risks are relegated to the physical realm in the form of acquired musculoskeletal disorders and the substantial repercussions associated with incurring sustained traumatic bodily injuries or disorders.
In the case of employers, the risks and losses are multifaceted and complex. The risks and losses for employers consist of decreased employee productivity, elevated levels of employee turnover, as well as an assortment of other potential risks to the business. Certain types and amounts of losses could also potentially contribute to the diminishment of a company’s public image. Further additional risks and losses include the various types of monetary costs associated with the deterioration of employee health when workers contract musculoskeletal disorders in relation to their participation in the ladder climbing activity.

Assumptions of the Study

The assumptions of this study include:

1. Wind tower ladders to be used in this study are all in proper working order and have been designed per applicable ANSI and OSHA standards.

2. The wind tower ladders to be included in this study are all of similar height and general dimensions.

3. The maintenance staff who climb the ladders are all experienced employees who have been trained in climbing and safety measures for ascending and descending ladders.

Limitations of the Study

The limitations of this study include:

1. Only ladders installed within wind towers of the same approximate size will be utilized for the purposes of this study.

2. Only employees who are experienced and trained in climbing wind tower ladders will be included in this study.
3. The observations and assessments in this study will only take place during one or two seasons during the calendar year. Therefore, the total effects of all seasonal weather conditions and temperature variations may not be observed as part of this study.

4. A thorough examination of the financial ramifications associated with changes in the wind power generation industry will not be included as part of this study.

5. Wind tower elevators and climb assist systems will not be fully and exhaustively evaluated as a major component of this study. Although, a general evaluation and assessment of these systems will be conducted in order to estimate potential reductions in physical stress associated with the use of these assistive devices in comparison to the physical burden accompanying the ladder climbing activity.

Definition of Terms

The following is a list of terms used in the study along with their definitions:

**Abduction.** The movement of a body part away from the center plane of the body.

Lifting the arm outward away from the body is an example of abduction.

**Adduction.** This is the movement of the body part towards the center plane of the body.

Lowering the arm toward the body is an example of adduction.

**Deviation.** The movement or position of a body part away from the neutral plane.

Bending the wrist with the hand bent towards the thumb is referred to as radial deviation.

Bending the wrist with the hand bent towards the small finger is referred to as ulnar deviation.

**Extension.** The movement of a joint that increases the angle between the bones.

Straightening the arm is an example of extension (Friend & Kohn, 2010).
**Flexion.** The movement of a joint that decreases the angle between the bones. Bending the arm at the elbow such that the hand moves closer to the upper arm region is one example (Friend & Kohn, 2010).

**Ladder.** The most basic means of ascending and descending a wind tower; a mandatory part of every tower (Avanti Wind Systems, 2017).

**Neutral Position.** The Neutral Position, also known as the neutral plane, is the normal and low-stress position of segmental physiological components. Maintaining the hand, wrist, and forearm at a 180-degree angle or in a straight and linear plane or dropping the hand, wrist, forearm, elbow, and upper arm at one’s side is an example of neutral planes (Friend & Kohn 2010).

**Pronation.** The turning of the forearm or wrist such that the hand rotates and the palm is facing downwards (Friend & Kohn, 2010).

**Repetitive movement.** The same movements occurring repetitively (Friend & Kohn, 2010).

**Rotation.** A movement in which a body part turns on its longitudinal axis. The turning of the head or arm is an example of rotation. Medial rotation is rotation toward the centerline of the body (Friend & Kohn, 2010).

**Rungs.** The horizontal parts of a ladder that climbers use their hands and feet on to ascend or descend the ladder. Rungs are mounted at equal spacings between ladder stiles (Avanti Wind Systems, 2017).

**Sequential movements.** A series of separate movements joined in a specific order to complete a given task (Friend & Kohn, 2010).
**Stiles.** The vertical portions of the ladder. Two stiles are connected by the rungs (Avanti Wind Systems, 2017).

**Supination.** The turning of the forearm or wrist such that the hand rotates and the palm is facing upwards (Friend & Kohn, 2010).
Chapter II: Literature Review

The need for maintenance workers to frequently climb the internal ladders of power generating wind turbine towers throughout their daily work-shift is placing these employees at risk of experiencing upper as well as lower extremity musculoskeletal disorders. Therefore, the purpose of this study is to identify the extent to which musculoskeletal disorders may occur among maintenance employees who are required to frequently climb wind power generation towers throughout their daily work-shift. This study has three primary goals. The first goal is to survey wind turbine power generation maintenance employees to determine the extent that they are experiencing various musculoskeletal disorder symptoms. The second goal is to perform an ergonomic assessment of the wind turbine maintenance personnel ladder climbing activities in order to quantify the extent of force, posture, repetition, duration, and temperature-related risk factors to which employees are typically exposed. The third goal is to compare the quantified tower maintenance employee risk factors against commonly-used ergonomic risk assessment tools.

Company XYZ is concerned that the need for maintenance workers to frequently climb the internal ladders of power generating wind turbine towers throughout their daily work-shift is placing these employees at risk of experiencing upper as well as lower extremity musculoskeletal disorders. In order to begin understanding, unraveling, and resolving this potentially complex issue, a review of the literature must be performed. The literature review begins with an explanation of ergonomics including its history, its purpose, background, and focus which makes it relevant to this study. The second section of the literature review covers the loss statistics for climbing-related occupations. This is to be followed by an exploration of work-related musculoskeletal disorders and cumulative trauma disorders. Subsequently, this portion of the
literature review will continue by identifying and providing examples of several different types of musculoskeletal disorders and the various characteristic symptoms or conditions associated with common work-related musculoskeletal disorders. Another major subject area to be incorporated into this literature review will be the ergonomic risk factors that may likely lead to musculoskeletal disorders. This section will delve into specific ergonomic risk factors that are associated with musculoskeletal disorders. Further, another section of the literature review will explore and describe several distinct assessment tools which are utilized in occupational ergonomic assessment, measurement, and evaluation-based activities. Next, the science of anthropometrics and the use of anthropometric data will be explained. Afterwards, a section on ergonomic hazard controls will describe the common types of controls and provide examples of their utilization. At the end of the literature review, a summary will be provided to recap the contents of this chapter.

**An Explanation and Background of Ergonomics**

An explanation of ergonomics may be initiated by first identifying the aim or purpose of ergonomics. Both the history and background will provide the necessary context for this effort in order to explain the purpose and focus of ergonomics.

**Definition of ergonomics.** The branch of knowledge that deals with the effects of the impact and influences that people, equipment, and work environments have upon one another is known as ergonomics (Bridger, 2009; Helander, 1997). Ergonomics is a term which draws its meaning from two distinct words of Greek origin which include “ergon (meaning work) and nomikos (meaning law)” (Tayyari & Smith, 1997). Ergonomics could be taken to mean the physical laws of nature that must be obeyed during the process of moving and using the human body to perform the functions of work. This is just one of several possible interpretations that
could be developed by translating the meaning of the Greek terms. Additionally, the American Conference of Governmental Industrial Hygienists (ACGIH) describes ergonomics as a “field that studies and designs the human-machine interface to prevent illness and injury and to improve work performance…It attempts to ensure that jobs and work tasks are designed to be compatible with the capabilities of the workers” (ACGIH, 2017, p. 182). Other terms or synonyms that are often substituted for the word ergonomics are the words human factors, human engineering (Ostrom, 1994), or human factors engineering (Tayyari & Smith, 1997).

**History and background of ergonomics.** After the end of World War II, a group of highly educated leaders from various academic fields including physiology, psychology, industrial hygiene, and other associated occupations gathered in 1949 to create a national ergonomics society in Oxford, England (Dul & Weerdmeester, 1993; Lehto & Buck, 2008). The technological development and progress which occurred throughout the 1900’s and two world wars presented unique challenges to humans as they interacted in new ways with contemporary systems and machines within their work environment (Bridger, 2018). This series of changes in the interaction between human beings and their work environments was not always practical, adequate, efficient, or an excellent fit between people and the systems within their working environments (Bridger, 2018; Grandjean, 1980). Ergonomics differentiates itself from other disciplines by utilizing practical, functional, and feasible solutions from a variety of branches of study to confront and resolve multiple issues of concern between working human beings and the situations presented by their surroundings within the context of the work environment (Dul & Weerdmeester, 1993).

**Purpose and focus of ergonomics.** If ergonomics could be said to have a basic underlying goal, its succinct objective would be “to design for ease and efficiency” (Phillips,
To be more specific, the intention of ergonomics is to proactively seek approaches and means for avoiding needless and burdensome tensions and pressures which tend to encumber human laborers or machine operators as they endeavor to function and thrive within occupational-industrial work systems (Bridger, 2018; Dul & Weerdmeester, 1993; Cohen, Gjessing, Fine, Bernard, & McGlothlin, 1997). This goal of relieving the workforce from unnecessary exertions of force, unsuitable body postures, inappropriate amounts of repetition, and other ergonomically unacceptable practices is then combined with an additional motivational emphasis (MacLeod, 1995). This additional proactive emphasis is essentially the pursuit of ergonomic harmony between the laborer and the occupational environment (MacLeod, 1995; Grandjean, 1980). Ergonomics strives to match the task to the worker and thus increase the capacity and efficiency of laborers by augmenting human potential and amplifying industrial yields (Bridger, 2018; MacLeod, 1995; MacLeod, Jacobs, & Larson, 1990). Ideally, this effort enables laborers to produce an ever-higher quality and increased quantity of products and services within the marketplace. To put it simply, the goal of ergonomics is to ensure that human operator stress and fatigue is minimized and to promote enhanced productivity (Phillips, 2000). The term “user-friendly” is equivalent to the state of being ergonomic in that user-friendliness would follow ergonomic principles (MacLeod, 1995). Expanding on this point in another way, MacLeod (1995) states that the opposite is also true, in that a condition or situation which presents itself as being unergonomic will result in unfavorable effects in regards to the health of workers. Thus, it could be surmised that one of the primary purposes of ergonomics is to make the work itself, as well as the physical dimensions and properties of the workplace (including the objects, tools, and machinery within) amenable to the people whose job it is to perform physical and mental occupational tasks. To take it a step further, the primary goal of
ergonomics is to promote the attainment of ideal relations between workers and their work environments (Byers, Hritz, & McClintock, 1978). This challenge of optimization requires the continual evaluation of occupations and industrial environments. Through the practice of applied ergonomics and by assessing, re-assessing, and using creative problem-solving techniques, sub-optimal situations in occupational settings can be converted or transformed into an improved state which is both favorable to the worker and ideal for the organization. This transformative path towards a reinvention and reorganization of the workplace should find ways to both uncover and reveal operational inefficiencies and then transform such work design issues into functional and ideal situations. According to Oxenburgh and Hagberg (2000), the optimization of ergonomics through an effective workplace ergonomics program can lead to measurable gains in the productivity for businesses and their employees.

With regard to the rewards of ergonomics, its advantages are numerous. The benefits of ergonomics include improved health and safety for employees, heightened job satisfaction for employees, heightened worker productivity, improved and enlarged production outputs, and enhanced profitability for the company as a whole (Kodak, 2004). When ergonomics is appropriately and effectively utilized, MacLeod (1995) asserts that it is capable of reducing employee injuries, resolving human errors, diminishing product defects, decreasing cost expenditures, ebbing the flow of employee turnovers and absenteeism, enhancing ease of use, amplifying and boosting employee morale, and improving overall quality (MacLeod, 1990). It is clearly evident that ergonomics is a tool that provides significant benefits for both employees and their employers. This feat is accomplished by improving employee health and safety while decreasing human and financial losses in addition to concurrently enhancing company profits and efficiency.
In order to realize the many benefits of ergonomics, purposeful actions must be taken to bring forward positive changes in the workplace. Before the desired benefits can be realized, it is recommended that employers first recognize the essential significance of ergonomic workplace design (Spur, Specht, & Herter, 1994). The authors Spur, Specht, and Herter (1994) identified a pair of important areas in ergonomic work design. The first is known as anthropometric design, which is a discipline that concerns itself with the measurable dimensions and statistical analysis of different human body types and sizes, correctly choosing beneficial working body positions over those that tend to be detrimental, as well as the measurement and comparison of human workers against the derived dimensions of their workplaces (Spur et al., 1994). The second major aspect of ergonomic design that they identify is referred to as “physiological job design” (Spur et al., 1994, p. 5). Physiological job design is chiefly focused on reducing the magnitude of and the extent to which heavy task loading amplifies the occurrence of muscular strains on the human body during work activities (Spur et al., 1994). In practice, the redesign of work activities redirects task actions towards enhanced levels of productivity and reduces injuries by identifying problem areas and finding novel or innovative solutions (Spur et al., 1994). Additionally, physiological job design encourages strategic alterations to the order in which the work is performed to further alleviate the potential for injury (Spur et al., 1994).

According to a report released in 2016 by the U.S. Bureau of Labor Statistics regarding the nonfatal occupational injuries and illnesses requiring days away from work that occurred during the 2015 fiscal year, a total of 356,910 individual musculoskeletal disorder cases represented 31 percent of all OSHA recordable workplace injuries for workers in the United States (Bureau of Labor Statistics, 2016). This statistical evidence readily signifies the need for
ergonomic improvements in the workplace and thus underscores the importance of gaining a greater understanding and appreciation for the major problems of musculoskeletal disorders that are currently afflicting the American workforce.

**Loss Statistics for Climbing-Related Occupations**

According to an international wind energy business news magazine Wind Power Monthly, wind turbine technicians who climb the tall fixed-ladders equipped in wind turbine towers are at risk from climbing (Crew, 2012). The article reveals that over time, climbing these exceptionally tall ladders which are regularly over 80 meters in height causes strains on the bodies of wind turbine maintenance technicians. (Crew, 2012). Moreover, the author discloses that injuries related to ladder climbing as well as exhaustion/fatigue are the foremost reasons for missed work days in the industry and additionally, that the annual job turnover rate for wind turbine technicians in certain locations is close to 25%, which is an alarmingly elevated level of occupational attrition (Crew, 2012). This is significant for the industry in fiscal terms as well because of the costly financial burden of replacing those technicians who are forced to change jobs, take a leave of medical absence, or resign due to injury. These human and financial costs can strain the resources wind project operations due to the substantial resource allocation and time investment dedicated towards hiring, training, and equipping wind turbine maintenance personnel (Crew, 2012).

In a 2018 survey of German offshore wind farm workers, the most frequently cited physical strain was climbing wind turbine ladders (Garrido, Mette, Mache, Harth, & Preisser, 2018). The study used a five-point answer response scale of always, often, sometimes, rarely, and never/hardly ever representing the numbers 1 through 5. Among all of the workers in different occupations in the offshore wind industry, workers participating in the study were a
group of wind turbine technicians, 27.2% of whom reported on a that they were always required to climb wind turbine ladders while 48.8% reported that they were often required to climb wind turbine ladders. In the study this adds up to a total of 76% of offshore wind turbine technicians who reported to the researchers that they were always or often required to climb wind turbine ladders (Garrido et al., 2018). This group had the highest reported incidence of physical strains from climbing was observed to be 27.2% reporting to either always being required to climb and 48.8% reporting that they were often required to climb wind turbine ladders. (Garrido et al., 2018) also found that because wind turbine technicians are exposed to higher levels of ergonomic risk factors than other offshore occupations, they are also at an elevated risk for developing MSDs. Thus, an enhanced focus and emphasis needs to be placed on the ergonomic concerns related to this particular working population of wind turbine technicians (Garrido et al., 2018). Garrido et al., (2018) established that compared to other workers in the offshore industry, wind turbine technician’s work is associated with higher levels of exposure to common MSD risk factors These factors included frequently having to climb wind turbine ladders, regularly carrying out tasks in unergonomic positions such as forward flexion of the torso and upper body, rotation of the spine, habitually working with their hands above their heads, as well as recurrently lifting and carrying substantial loads and equipment. Technicians are also habitually exposed to heat and cold stress, vibration, and working in confined and restricted spaces in less than less than ideal ergonomic situations and unfavorable bodily postures (Garrido et al., 2018). The authors comment that having to perform job tasks in such an awkward and cumbersome manner with adverse bodily postures, heavy lifting, and the overall general quality of the work being extremely physically challenging, especially for the type of work that
technicians perform, it is widely recognized that the conditions and occupational risk factors under which the technicians labor are well understood to relate to the development of MSDs. Although (Garrido et al., 2018) focused on the offshore wind industry workers and offshore wind turbine technicians, the authors do point out that there are a great deal of similarities in the type of work performed by offshore and onshore wind turbine workers, such as climbing very tall wind turbine ladders and working at extreme heights as well as the general environment of the wind turbine tower installation (Garrido et al., 2018). The process of climbing a vertical wind turbine ladder whether offshore or onshore is an extremely physically challenging task which is quite demanding on the body for several reasons including the fact that more muscular effort must be dedicated towards maintaining balance so as not to slip and fall (Garrido et al. 2018).

There are two basic alternatives to manually climbing (ascending and descending) the extremely tall vertical ladders inside of wind turbines. The first option, which is the least expensive and the most commonly utilized are powered climb assist devices which attach to the climbers’ harness and help to relieve some small portion of the weight, thereby decreasing the overall strain on the body incurred while climbing. The second option, and the most ergonomic option, service lifts (commonly referred to as elevators), virtually eliminates the strain on the body caused by climbing (Garrido et al., 2018). There are numerous risks associated with climbing on wind turbine tower ladders (Campbell-Kyureghyan, 2017). Although the wind industry has attempted to respond to some of the most obvious hazards of slipping, tripping, and falling, there remain many unresolved risks due to the characteristic recurrent and exceptional physical demands of the climbing activity (Campbell-Kyureghyan, 2017). Part of this is due to the unique nature of climbing the very lengthy vertical ladders which are integral to wind
turbines. According to Barron, Burgess, Cooper, and Stewart (2017), climbing vertical straight 90° ladders involves physiological costs and energy expenditure that is considerably and markedly higher when compared to the expenditure of physical energy which is utilized in more normal climbing activities such as that involved with ladders pitched at a 75° angle. Although the physical energy cost of climbing a vertical wind turbine ladder is not stated by Brauer (2006), Brauer does list the human energy costs associated with various normal physical activities that can be related to including walking slowly (900 Btu/hr. or 3.8kcal/min), cycling at 8-11mph (1360Btu/hr. or 5.7kcal/min), swimming at 1mph (1650Btu/hr. or 6.9 kcal/min), and continuous climbing of stairs (2860Btu/hr. or 12.0kcal/min). Certainly, it would be expected that if climbing normal stairs has this high amount of energy cost, then climbing a vertical 90° ladder would have an even higher human energy cost. According to Brauer (2006), work that is unduly heavy is classified as any activities that expend energy at a rate that is greater than 2,975Btu/hr. or 12.5kcal/min).

Wind energy jobs that require climbing vertical ladders in high wind towers are quite physically demanding and working in confined spaces may also have an impact on wind turbine technician health implications and this would be especially true for older workers (European Agency for Safety and Health at Work, 2013). Additionally, wind turbine technicians who are working at height without access to wind turbine elevators expose themselves to falls, slips, trips, and MSDs every time they want to return to ground level (European Agency for Safety and Health at Work, 2013). This means that regular work breaks may have to be delayed until the work has been completed before the worker is able to descend back down to the ground level via the ladder (European Agency for Safety and Health at Work, 2013).
Most of the unique hazards related to the ladder climbing activity are entirely removed from the job by the installation and use of wind turbine elevators (Campbell-Kyureghyan, 2017). Additional advantages of wind turbine elevators that should be extolled is that they help to retain employees, increase worker diversity, and most important of all, they eliminate muscular exhaustion and therefore also increase wind turbine technician production and efficiency (Campbell-Kyureghyan, 2017). Furthermore, wind turbine service lifts also allow wind turbine technicians to safely haul work materials up and down the wind turbine tower without having to carry them up a ladder or hoist them from above (Campbell-Kyureghyan, 2017). Campbell-Kyureghyan (2017) concludes by stating that the costs of wind turbine elevators are easily outweighed by the benefits and enhancements to wind turbine technician safety, efficiency, and workplace production and should therefore be installed in all wind turbine towers.

Unfortunately, many earlier model wind turbine towers still in use either never had a functional service lift installed or lack a functioning elevator/service lift for any other number of reasons – usually financial. This could be for several reasons, for instance, some towers might not have been built to accommodate a service lift, or the tower could have been built without an elevator to save on startup costs and an elevator was never installed or retrofitted because of the costs involved with doing so. (Garrido et al., 2018).

As briefly mentioned in Chapter I, the Burau of Labor Statistics does not currently provide or make available data which is specifically related to the occupational injuries and musculoskeletal disorders incurred by wind turbine technicians. However, the musculoskeletal disorder and injury data that is readily available for other occupations with similar types of manual labor tasks may be of interest in relation to an ergonomic study of wind turbine technicians. Not only may this type of data for other occupations be noteworthy, it may also
support an extrapolation or inference which leads to an enhanced understanding of the potential for occupational injuries and musculoskeletal disorders that could be incurred by wind turbine technicians. Most noteworthy of the human loss statistics provided by the BLS are the incidence rates and number of cases of musculoskeletal disorders for three categories of workers. The three occupations that align with work that is performed by wind turbine technicians include firefighters, bus and truck diesel mechanics, as well as laborers and freight, stock, or material movers. Not surprisingly, firefighters have the highest rate of all occupational musculoskeletal disorder cases for 2016, with a rate of 181.9 per 10,000 full time workers and a total of 5,860 reported cases of musculoskeletal disorder injury that resulted in days away from work (Bureau of Labor Statistics, 2017). Visual evidence indicates that both wind turbine technicians and firefighters climb high ladders in less than ideal environmental/temperature conditions as part of their jobs while wearing heavy protective clothing and safety equipment. The ladders that wind turbine technicians tend to climb are completely vertical and likely create more stress on the body than the ladders that firefighters generally climb which tend to be at less than a 90-degree angle. Admittedly, all of the specific job duties of firefighters and wind turbine technicians may not be similar, but certain occupational tasks involved in both professions do generate situations that are similarly physically stressful to the musculoskeletal system.

The second occupation that may be relatable to wind turbine technicians includes bus, truck and/or diesel mechanics who experienced an incidence rate of 93.3 reportable musculoskeletal disorder injuries per 10,000 workers in the year 2016 (Bureau of Labor Statistics, 2017). Both automotive mechanics and wind turbine technicians depend on the use of their hands and hand-held tools to operate and repair complex machinery. Finally, a third occupation worth pointing out which may possess similar occupational tasks to that of wind
turbine technicians is the category of laborers and freight, stock, and material movers who experienced an incidence rate of 122.8 musculoskeletal disorders per 10,000 workers in the year 2016 (Bureau of Labor Statistics, 2017). This group also managed to accrue a total of 24,810 recordable musculoskeletal disorder injuries in calendar year 2016 which resulted in lost time with days away from work (Bureau of Labor Statistics, 2017). This broad occupational category of workers tends to use their bodies to physically move and manipulate potentially large and heavy objects. In comparison, wind turbine technicians use their bodies to carry moderately heavy tools and replacement parts while also climbing up exceedingly long vertical ladders. The core concept is that there are multiple types of occupations that provide reasonable comparisons to the occupation of a wind turbine maintenance technician. Thus, the previously discussed professions perform a variety of reasonably comparable and relatable physical job tasks which generally present the risk of sustaining occupationally-related musculoskeletal disorder type injuries. According to the European Agency for Safety and Health at Work, (2013) the general occupational safety and health issues related to both offshore and onshore wind turbine industry include working in isolated and remote locations, weather extremes and unpredictability, confined space issues, electrical hazards, exposure to dangerous substances, falls, physical stressors, ergonomic postural issues, and musculoskeletal disorders. Musculoskeletal disorders are then the focus of the following section of this literature review.

**An Explanation of Musculoskeletal Disorders (MSDs)**

Hamrick (2006) states that musculoskeletal disorders are both a common and costly phenomenon prevalent in the American workplace. According to the Encyclopedia of Disability and Rehabilitation, musculoskeletal disorders include a wide variety of maladies and ailments caused by physio-mechanical disfunction or deformation in skeletal bone and soft tissues soft
tissues such as muscles, tendons, and ligaments which results in pain, discomfort, malfunction and loss of physical capacity (Klaiman & Hicks, 1995). Obviously, musculoskeletal disorders may be both serious and life altering conditions that affect the ability of individuals to work in their usual manner and full capacity, thus causing an early exit from viable employment opportunities. These incidents of musculoskeletal disorders seriously impact upon an employee’s financial stability and ability to earn a living in a given occupation, thus decreasing their capacity to provide for their families and/or find employment elsewhere. In a cascading effect, the employer is then negatively impacted through the loss of an experienced and perhaps talented employee, which then presents further negative potential ramifications for the financial position of the company given the need to replace that member of the workforce with a new employee. The costs of money and time spent in this manner can be extensive and financially exhausting for businesses, to say nothing of the incalculable toll of human suffering involved in these adverse occupational situations.

An introduction to MSDs. The human body contains multiple complex systems that are comprised of numerous components including bones, muscles, connective tissues, tendons, ligaments, and cartilage; all of which must work together in a complex and sophisticated manner in order for an individual to perform each of their job duties (Kumar, 2008; Ostrum, 1994). With sufficient concentrations of force and/or repetitive stress and tension, any component of this complex physiological system may break down and lead to failure or malfunction of that system, which also has the potential to causing a cascade of sequentially progressive failures in ancillary and/or adjacent connected systems (Kumar, 2008; Marras, 1997). When any part of a system fails, it can affect other connected systems which in turn could lead to a more complex systemic failure. This is because musculoskeletal disorder injuries have a basis in the biomechanical
workings of the human body (Kumar, 2008). If an individual consciously or unconsciously compensates for the effects of a musculoskeletal disorder, it would also be possible or even likely to promote further strain on other components of the musculoskeletal system while making up for a loss of function elsewhere in the body (Kumar, 2008). For instance, if a person had one or both knees that were experiencing musculoskeletal disorder symptoms, that person might not use proper lifting form by bending at the knees and using the powerful leg muscles to lift the weight of heavy objects. Thus, the individual might develop a habit of using the less powerful muscles of the lower back to pick up objects (forward flexion of the spinal column) which could then lead to a musculoskeletal disorder of the spine and lower lumbar region or even lead to a more complex failure of other connected parts and components of the musculoskeletal system.

Definitions of MSDs. For at least the past two decades, injuries to humans in the workplace as a result of ergonomically inadequate workplace designs have been described by various terminology (Ostrom, 1994). An extensive vocabulary of formally recognized terms have been used as alternative expressions or applied as synonyms for describing MSDs. Various examples include “Cumulative Trauma Disorders (CTDs)” (MacLeod, 1995, p. 104); “Work-Related Musculoskeletal Disorders (WMSDs)” (Cohen et al., 1997, p. 1); “Repetitive Motion Injuries (RMIs)” (Peate & Lunda, 2002, p. 1); “Repetitive Motion Syndromes” (Ostrom, 1994, p. 5); and “Repetitive Strain Injuries (RSIs)” (ACGIH, 2017, p. 182). In the context of this literature review, musculoskeletal disorders may be referred to as MSDs, CTDs, and the other terminology or synonyms listed above and may be used interchangeably with the term MSDs as well unless otherwise noted.

According to Cohen et al., (1997), the term MSDs refers to musculoskeletal disorders which have been appreciably furthered by and/or emanate directly from the execution of job
duties at the place of employment. The effects of MSDs are made more detrimental, persistent, and enduring from the circumstances and factors affecting the employment setting (Cohen et al., 1997). MSDs also include “disorders of the nerves, joints, cartilage, or spinal discs” (Cohen et al., 1997, p. 1). MSDs can occur in a myriad of different ways, including the slow, steady, and persistent loss of function over a long period of time or a severe and sudden incident such as slips trips and falls which cause immediate injuries to the physiological system, especially resulting in injury and pain to the lower spine and attending muscular structure (Cohen, et al., 1997). According to Tayyari and Smith (1997), musculoskeletal disorders are pervasive, and no profession or industry is exempt from the incidence of MSDs. Ultimately, it seems that the responsibility of confronting and tackling the problem of widespread employee MSDs falls squarely on the shoulders of employers and the business community.

Certainly, the power to reverse the course of the work-related MSD epidemic rests firmly in the hands of employers or company decisionmakers (MacLeod, 1995). According to MacLeod (1995), all employers have a responsibility to implement ergonomic principles to correct their workplace and make it suitable for the employees working at their worksites or establishments. It is evident that the endorsement and support of ergonomic programs by company leaders and decisionmakers is imperative for the success of ergonomic programs (Kearney, 2008). The decisionmakers are those who have the power to impact a positive change to their own organizations’ and industries’ workforces and include small business proprietors, owners and managers of international establishments, working organizations, job-creators, and employers in general. In order to improve and rectify the current sub-optimal un-ergonomic situations remaining in the workplace, decisionmakers must first understand that the problem exists and then decide to implement favorable modifications to the work process and
environment. This understanding of the problem needs to be clearly explained, rationalized, conveyed and presented to management (Pulat, 1992). It is apparent that decisionmaker endorsement and commitment is extremely important (Pulat, 1992). Then, with the support and backing of decisionmakers, the implementation of ergonomic programs and practices can provide ample advantages for all parties involved. According to Pulat (1992), not only should decisionmakers care about implementing successful ergonomics programs because it is the morally right thing to do, but there is also a tremendous potential cost component to the equation as well. Hamrick (2006) asserts that there are enormous costs associated with musculoskeletal disorders and that employers should be highly motivated from a business and financial standpoint to become involved and interested in monitoring, managing, restraining, and reversing these incidents and the severity of the costs before they develop into an acute and widespread crisis. These costs include significant ramifications for society as a whole by misappropriating valuable resources such as human labor, time, and financial resources.

**Examples, descriptions, and symptoms of MSDs.** One of the most widely recognized MSDs is Carpal Tunnel Syndrome. Carpal Tunnel Syndrome could be best described as a compressive force acting on the median nerve which runs through the carpal tunnel of the wrist. This compression of the median nerve is exerted by inflamed tendons which also pass through the carpal tunnel as movements of the wrist and hand are made (Ostrum, 1994). Symptoms related to carpal tunnel include tenderness in the inflamed area of the wrist well as the irritating and potentially debilitating phenomenon of pins and needles as well as numbness in the palm and fingers (Bridger, 2018).

Epicondylitis, commonly known as Tennis Elbow or Golfers Elbow, is common to sports enthusiasts such as in tennis, golf, baseball, or bowling, and also occurs in construction
occupations such as carpenters (Kroemer, Kroemer, & Kroemer-Elbert, 1994). Epicondylitis is caused by forcible contact and activities such as such as the hammering motions of a carpenter or quick and sometimes awkward movements or repetitive rotations of the lower arm (Ostrom, 1994). Examples of this might include an athlete pitching a baseball, serving a tennis ball, rolling a bowling ball, or swinging a golf club. Such activities may result in inflammation and irritation of the tendons connected to the epicondyle where the humerus is attached to the elbow (Ostrom, 1994). This condition is also associated with the presence of excessive supination, pronation, rotation, extension, as well as force on the forearm and wrist (Kroemer et al., 1994).

Symptoms of this disorder include pain and loss of elbow mobility (Bridger, 2018).

Tendinitis is inflammation of the tissues of the body; specifically, tendons whose function are to attach bones to muscles (Ostrom, 1994). This disorder can manifest itself in multiple locations wherever tendons are located in the human body. An all too common example of this musculoskeletal disorder would be tendonitis of the rotator cuff within the shoulder joint (MacLeod, 1995). The rotator cuff area is an exceptional and intricate zone within the upper extremities of human body. It provides the shoulder joint and the human arm with a unique degree of flexibility. Rotator cuff tendinitis decreases this freedom of movement and the symptoms of this illness include a reduction in the shoulder joint’s mobility as well as the presence of pain and weakness (Bridger, 2018).

Tenosynovitis, not to be confused with tendinitis, is a disorder typically caused by quick and repeated motions of fingers and hands so as to cause injury (Bridger, 2018). As a result of these recurrent motions of the fingers and hands, the synovial sheaths which normally act as a protective layer surrounding the tendons begin to become inflamed and then emit a surplus of synovial fluid which further exacerbates the situation by causing pain as the resultant swelling
creates tightening and restriction of movement of the tendon within its sheath (Bridger, 2018). Under normal conditions, synovial fluid is a beneficial lubricant that helps tendons to move smoothly, but excess synovial fluid creates swelling and pain in the areas which it occurs (Woodside & Kocurek, 1997). Left unchecked, the repetition of this condition can create scar tissue which further hampers tendon movement and lowers the ability of the tendons to perform normally (Bridger, 2018). Tenosynovitis usually occurs in the back of the hand and the wrist and can also lead to carpal tunnel syndrome (Woodside & Kocurek, 1997). De Quatrain’s Disease is another notable musculoskeletal disorder of a similar type in which the tendon sheath of the thumb becomes inflamed. This disorder is generally caused when the thumb is used to perform excessively forceful gripping, pinching, and/or twisting motions that cause undue friction between the two tendons of the thumb and their shared sheath (Woodside & Kocurek, 1997). Another type of synovitis dealing with the lower extremities is patellar synovitis, a condition wherein the tissues of the knee become inflamed, which in turn creates excess synovial fluid, thus resulting in pain and loss of functional mobility (MacLeod, 1995).

Yet another musculoskeletal disorder is called bursitis, which is a condition affecting the bursae. Bursae are essentially small liquid packets that exist in multiple locations, such as the shoulders and elbows in order to serve the purpose of helping the tendons to move smoothly within the human body (MacLeod, 1995). Bursae could also be said to perform a function much like a soft protective cushion which moderates friction, reduces contact, and buffers the impacts between the skeletal bones and the muscles and/or tendons they would otherwise come into contact with during bodily movements (Bridger, 2018). In regard to the numerous points on the body in which bursitis could potentially occur, Bridger (2018) states that there are roughly 150 bursae distributed at physiologically advantageous locations throughout the human body. In
regards to the condition itself, bursitis is simply an inflammatory condition of the bursa sacs (MacLeod, 1995). Diagnostically, bursitis and tendonitis differ on both a musculoskeletal structural basis and in the symptoms that result (Bridger, 2018). The discomfort resulting from bursitis is that of a dull low-level pain which lingers over a long period of time as opposed to tendonitis which is generally experienced as a more sudden and intense pain (Bridger, 2018). An example of a common particular type of bursitis is one that specifically affects the knees. This is known as subpatellar bursitis, an inflammation and swelling of the patellar bursa, which is a common affliction for plumbers, carpenters, floor layers and any other occupations that have a tendency towards spending long periods of time working on their knees (MacLeod, 1995). Yet another type of bursitis solely affects the hip and is known as trochanteric bursitis. This is caused by prolonged periods of standing and carrying excessive weight which leads to inflammation of the bursa at the hip joint (MacLeod, 1995).

There are numerous other MSD’s that deserve mention which involve the neck, back, ligaments, muscles and fascia. Examples of neck and back MSDs include disorders such as tension neck syndrome. The symptoms of tension neck syndrome include a perpetual and consistent soreness of the cervical spine and neck, which is frequently connected to risk factors such as static loading, awkward or forced postures, and muscular tension or stress held in the muscles surrounding the neck (MacLeod, 1995). MSDs can also include issues such as posture strain, which is caused by excessive flexing and stretching of the muscles and tissues of the neck as well as the area surrounding the base of the neck (MacLeod, 1995). A more serious and somewhat well-known adverse spinal condition known as mechanical back syndrome is caused by the deterioration of the small stabilizing joints of the vertebrae (MacLeod, 1995). Another very unfavorable condition within the spinal column is referred to as degenerative disc disease.
This condition consists of a long-term deterioration, constriction, and solidifying of the spinal discs as well as surface fracturing upon the exterior of the spinal discs (MacLeod, 1995). Possibly the most well-known of these adverse spinal conditions is the herniated disc which consists of a bulging spinal disc that may impinge on a nearby nerve, thereby causing shooting pain, sensitivity, and/or numbness from the pinched nerve (MacLeod, 1995).

Other types of conditions worth mentioning include various disorders of the ligaments, muscles and facia. Fundamentally, ligaments are tough and flexible fibrous tissues that connect and reinforce bones (MacLeod, 1995). Common types of ligament-related MSDs mostly consist of sprains with the most ordinary of such being a sprained ankle. A sprain is essentially the over-stretching and tearing of the ligaments. A common muscle-related MSD would include a disorder regularly experienced by jogging enthusiasts which is known as shin splints. Shin splints are often misunderstood as a disorder of the shin bone (tibia) itself, when in fact it is a disorder that affects the muscular tissues at or near the point at which they make contact with the surface of the tibia. The disorder essentially consists of numerous tiny tears in the muscle which is being pulled away from the shin bone, leading to inflammation (MacLeod, 1995). Possibly the most common issue related to the muscles is a general muscle strain, which is simply excessive stretching or overuse of a muscle (MacLeod, 1995). Plantar Fasciitis is the most common and recognizable form of a facia-related MSD. This disorder is the result of excessive pressure on the ligament that supports the arch, thus creating inflammation, heel pain, and stiffness (MacLeod, 1995).

Although certain lower extremity MSDs have been previously mentioned, Lavender and Andersson’s (1999) ergonomic literature concentrates on mitigation and control of spinal and upper body work related musculoskeletal disorders and mostly ignores lower body occupational
musculoskeletal disorders. Moreover, Lavender and Andersson (1999) suggest that this inattention to musculoskeletal disorders of the lower extremities could be caused by a decreased recognition and comprehension of the incidence and significance of work-related musculoskeletal disorders of the lower body extremities.

The focus of the following literature review section will involve the work-related effects of the fore mentioned musculoskeletal disorders as well as the reasons that such ailments occur.

**Ergonomic Risk Factors Which May Lead to MSDs**

In defining the risk factors for MSDs, there are several commonly agreed-upon types of physical activities and environmental or situational conditions which all are readily understood to introduce and invite the occurrence of MSDs. These occupationally-based ergonomic risk factors tend to be remarkably influential indicators that precede and initiate (or directly contribute to) an individual’s chances/likelihood of acquiring a musculoskeletal disorder. Additionally, prolonged or repeated exposure to these risk factors tends to increase an individual’s susceptibility to developing significant and sustained resultant MSD symptoms (Cohen et al., 1997). Numerous risk factors have a propensity to be found in the workplace and tend to negatively affect those individuals who are exposed to such (Cohen et al., 1997). These risk factors are a well understood concern among educated practitioners of ergonomics (Cohen et al., 1997). Through their training, ergonomic professionals might be expected to have a reasonably comprehensive level of understanding related to these factors (Cohen et al., 1997). Similarly, among occupational safety and health professionals as well as industrial hygienists, there also seems to be an understanding of these risk factors (ACGIH, 2017; Cohen et al., 1997). The primary risk factors commonly outlined throughout the ergonomic literature and within the ergonomic profession are known as force, posture, repetition, duration, vibration, and thermal
stress. Somewhat less frequently listed and yet commonly understood MSD risk factors include contact stress and static loading. Static loading is at times characterized as a subset of posture-based risk factor; or conversely it may be categorized and grouped with other risk factors related to activity duration times. In addition, it should be noted that repetition (or rapid repeated body movements) are also occasionally referred to as task frequency rates or job cycle times.

According to Lemasters and Atterbury (2011), the term work-related musculoskeletal disorders (WMDs) is utilized to indicate a variety of ailments that are similarly named or referred to as cumulative trauma disorders (CTDs), overuse syndromes, and repetitive strain injuries (RSIs). It would be hoped that this does not lead to confusion. Thus far, for the sake of clarity, the terms MSD and WMSD have been used almost exclusively during the majority of this literature review, but that does not mean that the terms CTD and RSI are less suitable or appropriate for describing the conditions herein. All these terms refer to conditions that involve symptoms usually localized in a specific area of the human body and result in the occurrence of pain discomfort and/or a pins and needles sensation (Lemasters & Atterbury, 2011). In summary, the American Conference of Governmental Industrial Hygienists conveys the point of this section quite satisfactorily and concisely in declaring that the term musculoskeletal disorder is meant to represent persistent physical problems and conditions which exist in the muscles, tendons, nerves, and connective tissues. These conditions are produced by all of the typical ergonomic risk factors such as excessive force, vibration stress, contact stress, unduly recurrent or hurried repetitive motions, awkward postures, and temperature extremes (ACGIH, 2017).

**Explanation of ergonomic risk factors.** Before the work can begin to resolve the trouble of work-related MSDs, there first should be a recognition of and comprehension of the MSD related problems and challenges which are confronting the workforce. According to
Hamrick (2006), the act of endeavoring to mitigate the manifestation and incidence of occupationally generated musculoskeletal disorders necessitates an appreciation and awareness of the influential aspects of those dynamic workplace situations and risks which promote the occurrence of MSDs. Though, before a thorough understanding of the foundations of musculoskeletal disorders can be gained, the sources of the problem must be named. In ergonomics, this source is called a risk factor. Risk factors are a class of fundamental actions, events, or exposure types that influence the probability or threat of incurring MSDs. Simply stated, the elements and circumstances which escalate and proliferate the probability of MSD prospects are referred to as risk factors (Hamrick, 2006). Moreover, the ergonomic risk factors that take place in occupational settings where MSDs are attributed to the physical jobs of workers are referred to as occupational risk factors (Hamrick, 2006).

The ergonomic risk factors that will be covered in the following several sections include force, posture, repetition, duration, vibration, static loading, temperature extremes, and contact stress. In 1997, while working in cooperation with many other contributors for the National Institute for Occupational Safety and Health (NIOSH), Dr. Bruce Bernard completed a review of the literature on the relationship of musculoskeletal disorders to the work environment. His literature review-based research indicated that there is evidence for MSDs being caused by the presence of certain risk factors (National Institute for Occupational Safety and Health, 1997).

**Force.** Force may be generally understood as the use of muscular strength to perform work and the expenditure of effort to create physical movement or action. The amount of bodily effort or force required to complete a physical job duty or task is directly related to the muscular effort that must be applied by the employee to perform that same job duty or task (Grant, 2011). Force is commonly the first risk factor in any list of ergonomic risk factors for work-related
musculoskeletal disorders. Observationally, it is reasonable to comprehend why the risk factor force typically makes the list because accomplishing specific physically demanding job tasks typically requires the exertion of extreme or undue force (Tayyari & Smith, 1997). As the use of force to perform certain tasks is accepted or encouraged in the workplace, it leads to an intensification of physical demands on workers by placing additional stresses on their bodies. It is reasonably understood that the intensification of forces necessitates an increase in bodily requirements such as heightened physical effort as well as additional physiological adjustments necessary to sustain an escalating amount of exertion required by a task (Cohen et al., 1997). In forceful work situations or conditions, there are definite external observations to be made, but it is equally important to understand the internal workings and mechanics of the human body as it experiences the influences of forceful work-related activities. This is necessary because during forceful work, the body may need to accept a significant burden. In fact, the weight or burden placed on numerous bodily tissues can amount to hundreds of additional pounds (Putz-Anderson, 1988). The occurrence of repetitive forceful work activities leads to even more strain and pressure on the body (Cohen et al., 1997). Then, when muscular energy is progressively expended in reaction to a heavy work load, the blood circulation to the muscles is decreased and consequently promotes increasingly accelerated muscular exhaustion (Putz-Anderson, 1988).

Simply stated, the situation occurring inside the muscle tissues can be explained in that forceful occupational exertions which are performed over a period of time may eventually pave the way towards muscular exhaustion, and ultimately leads to the occurrence of MSDs. As the energy used to propel muscles is amplified in reaction to a high job task load, the blood circulation to the active muscles is diminished thus hastening the onset of muscular fatigue (Grant, 2011). As a consequence, if force-induced fatigue is left unchecked, it could initiate or
influence the occurrences of work-related musculoskeletal disorders. For instance, in reference to force as a risk factor, Cohen et al. (1997) affirms that extended or repeated incidents of this kind may not only promote the natural sensations and feelings of fatigue, but that such events could contribute to musculoskeletal disorders if the worker is not provided with sufficient time to allow his/her body to rest and recover from the exhaustive physical work. This is an unfortunate fact for many workers who are placed in certain work situations that require forceful actions or movements without an appropriate allotted amount of time for the body to revitalize itself between tasks or work shifts. According to Putz-Anderson (1988), in job situations where the bodily force requirements are high, the time that it would take to recuperate from the work may in fact surpass and exceed the actual amount of time spent working during a given work shift or a typical work day. This means that for certain forceful occupations or job tasks, workers do not have enough time away from work to allow for sufficient recuperation and rest before they must return to performing forceful job tasks on the following day of work. Realistically, this means that the workers’ bodies never fully recover and repair the affected soft tissue before their next scheduled shift. Over time, this would undoubtedly be a regretfully unpleasant situation to be subjected to as the body essentially wears down over a given period of time. It should not really come as a surprise then to find out that when workers are increasingly denied or deprived of adequate or appropriate time to heal their bodies from forceful work, injuries to the soft tissues will emerge (Putz-Anderson, 1988) and with continued exposure these soft tissue injuries may potentially develop into full blown musculoskeletal disorders.

Clearly there appears to be agreement that force is an ergonomic risk factor as well as a primary contributor to the occurrence of work-related musculoskeletal disorders (WMSDs) per the associated synonyms (i.e. CTDs). Simply stated, the requisite forces that are necessary to
complete/accomplish numerous assorted occupational tasks is likewise a significant and potentially decisive influential component which contributes and heavily influences the initiation of cumulative trauma disorders and musculoskeletal disorders (Putz-Anderson, 1988). Moreover, work tasks and occupations that demand undue or extreme amounts of force have a tendency to strain and harm the muscles and tendons, thus fostering further risk of acquiring/experiencing a cumulative trauma disorder or sustaining musculoskeletal disorders (Tayyari & Smith, 1997). Consequently, it’s no wonder that force is one of the most common and notable ergonomic risk factors which exists in numerous workplaces and heavy task workload situations. According to the European Agency for Safety and Health at Work (2013), gaining access to the nacelle naturally means that climbing very tall vertical ladders is a necessity when there is no elevator or service lift available for the workers to use. Workers may have to ascend and descend the tower several times during a day of work and this generates a high physical load on workers, resulting in both physical exhaustion and musculoskeletal disorders (European Agency for Safety and Health at Work, 2013). Ascending and descending wind turbine ladder multiple times per day is an immense amount of climbing and performing the task while carrying up 10kg (22 lbs.) or more of equipment would tend to make the climb challenging to say the least, and what would be even more demanding would be to transport the load back down the turbine ladder when work is finished (European Agency for Safety and Health at Work, 2013). Even with the comparatively decent wages for the occupation, many wind turbine technicians only stay on the job for 3 to 4 years (European Agency for Safety and Health at Work, 2013). The solution to this problem suggested by the authors is for employers to reduce staff turnover and avoid musculoskeletal disorders and injuries by equipping the towers with wind turbine elevators (European Agency for Safety and Health at Work, 2013).
Posture. In casual terms, bodily posture may commonly be understood as how individuals tend to carry themselves when sitting, standing, or walking. In formal terms, an ergonomic assessment of a person’s posture can be a much more complex topic than simply maintaining optimal spinal alignment. From the neck down to the feet, every part of the human body is subject to the matter of ergonomic posture concerns. According to Tayyari & Smith (1997), it does not matter whether a person is sitting, standing, leaning, or actively moving because if they are assuming an unsuitable or inappropriate working body posture or being forced into any uncomfortable bodily position or configuration, it will likely cause that individual to be at a much higher risk of developing a cumulative trauma disorder or musculoskeletal disorder. An incredibly significant potential negative result of physically assuming unsuitable postures is that it can lead to spinal problems (McCormick and Sanders, 1982). This is because improper postures such as hunching over, stooping, lifting, and improper carrying of heavy objects tends to wear out the delicate discs that act as cushions for the spinal column. Although the spinal column is not the only area of concern. Awkward postures come in many forms and should be particularly concerning for those individuals that perform repetitive tasks due to the frequency of body movements and the overall cumulative negative effects this has on the body (Keyserling, Punnett, & Fine, 1987). If they are not controlled, awkward postures can lead to localized fatigue and contribute to the development of musculoskeletal disorders (Keyserling, Punnett, & Fine, 1987).

Numerous occupational tasks could be considered to possess or contain sub-optimal posture situations which pose a manifest hazard to workers. The specific hazard of sub-optimal un-ergonomic postures is that such may produce or contribute to the occurrence of WMSDs. According to Putz-Anderson (1988), a variety of occupations necessitate that the employee
physically assumes awkward or uncomfortable body position(s) which presents substantial and problematic biomechanical stresses to the joints of the upper extremities and the adjacent muscles, tendons, and ligaments. Putz-Anderson (1988) suggests that unnatural posture is a substantial and important concern in the occurrence of cumulative trauma disorders or musculoskeletal disorders. Putz-Anderson (1988) defines and outlines postural problems in straightforward and relatively easy to understand terms that are readily recognizable. For example, Putz-Anderson (1988) states that unsuitable postures may include any working position where the whole body or any part of the body is placed into a stationary, rigid, immobile, fixed, unnaturally forced, restricted, limited, or constrained physical posture. Other primary concerns include any working situations or postures that specifically include static loading of the body (Putz-Anderson, 1988). Additional postural concerns include those that overwork the soft tissues of the body such as the muscles, tendons, and ligaments, as well as those that unevenly or asymmetrically overburden the joints of the body with weight or other stressful factors (Putz-Anderson, 1988). In a supporting statement, Kearney (2008) adds that ergonomically awkward and cumbersome postures are linked and correlated with amplified risks of incurring bodily harm or injuries. Further, the risk of incurring an ergonomic injury is strongly amplified by increased deviations of the joint from the baseline neutral and natural position (Kearney, 2008). There are many examples of unnatural or awkward postures in workplace scenarios. For example, an employee might be asked to climb onto or crawl into a space that is not large enough to stand up in and perform work, and thus bodily contortions must occur in order to fit into the space and move the limbs as well as the spinal column into awkward and dangerously uncomfortable positions in order to accomplish a certain task. Undue bending, twisting, and reaching have been found to be associated with the onset of lower back pain injuries in industry (Snook, 1987).
According to Snook (1987), twisting of the torso and spine which results in lower back pain has been connected in 9% to 18% of cases, while forward flexion or bending of the torso has been connected to 12% to 14% of lower back pain incidents (Snook, 1987). Twisting of the spine and the torso is frequently result of performing tasks in congested or confined work areas where there is a lack of space available to easily reposition or turn one’s feet (Snook, 1987). Other examples could include a workplace design that does not naturally conform to the physical needs of the workers body. Examples such as this may include a rigid vertical ladder that is either too long, narrow, and/or awkward to climb with any occupational regularity. Another example could include a workstation that is too short or excessively high for an individual worker so that again, the employee must contort his/her body into a position that will fit into the work area while placing limbs/appendages into awkward and stressful positions of flexion, extension, and other deviations from the neutral and natural body position. There are also many relevant examples of ergonomic and postural concerns when it comes to wind turbine towers and wind turbine ladders. According to RenewableUK (2015), deficient or inferior ergonomic conditions in wind turbine towers increases the risk of injury to workers in the short term from sudden injuries and in the long term from the development of work-related musculoskeletal disorders. Examples include regular climbing of vertical wind turbine ladders when there is no wind turbine elevator equipped, as well as the typical lack of working space to move around and work on both the yaw deck (just below the nacelle) and in the nacelle itself (RenewableUK, 2015). The strain induced by recurring ladder climbing activities combined with the naturally restrictive space of these upper wind tower environments can induce the development of MSDs and work-related injuries (RenewableUK, 2015). Technicians also suffer from problems related to accessing physical components of the wind turbine to be serviced can be very uncomfortable and awkward
(RenewableUK, 2015). It may frequently involve postures such as kneeling, crawling around on the knees, as well as reaching, bending, and twisting of the spine which increases the strains involved in performing technical/mechanical servicing and repair duties (RenewableUK, 2015). The combination of physically stressful ladder climbing to reach the yaw deck and the nacelle in order to perform maintenance activities combined with the severely restricted space in which the maintenance is conducted puts technical workers at a higher risk of contracting MSDs (RenewableUK, 2015).

**Repetition.** Repetition is simply the act of repeating a certain activity and is considered to be a contributor to the occurrence of MSDs. Work that necessitates an employee to accomplish tasks while using exceedingly repetitive movements also contributes to the development of cumulative trauma disorders or musculoskeletal disorders (Putz-Anderson, 1988). The more repetitive that a given job or task is, the more often the muscles will need to repeatedly contract and release in a continually repetitive cycle (Putz-Anderson, 1988). Essentially this means that jobs which demand elevated rates of repetitions will require increased muscular effort, which in turn will necessitate additional time for rest and recuperation than jobs and tasks that are less repetitive (Putz-Anderson, 1988). Thus, high levels of repetition make for one of the main factors in the development of WMSDs. As an example of a highly repetitive task, Cohen et al., (1997) states that any task cycle times of 30 seconds or less would meet the definition for a high rate of repetition. Unfortunately, a perceived level of safety in tasks that are considered light and easy work may lull the worker (and the employer who sets up the work) into a false sense of security. In this way, the jobs and tasks that require an elevated rate of repetition may develop into sources of physical trauma even though the actual forces required to perform
the job are considered to be what is generally accepted to be within the safe and tolerable working limits (Putz-Anderson, 1988).

**Duration.** Duration is the time required to complete a task or the length of time spent performing a specific task. As a risk factor for musculoskeletal disorders, duration relates to the length of time that a worker is constantly subjected to an ergonomic risk factor (Cohen et al., 1997). Duration as a risk factor is likely well understood by many. Any individual who has worked a job where certain potentially strenuous physical tasks are required throughout the day would likely understand how such vigorous work may wear a person down over the course of a day, a week, a month, a year, or even longer. According to Cohen et al. (1997) occupational tasks that necessitate using the same muscles or groups of muscles repeatedly over a period of time and in an unchanging fashion tend to intensify the probability of generalized and localized muscle fatigue (Cohen et al., 1997). Essentially, the more recurrent and protracted the period of time that work continually takes place, the more time that will be necessary for the worker to rest and recuperate (Cohen et al., 1997). In regards to whether a 10-hour or 12-hour day would be any riskier than a standard 8-hour day, a 2004 document published by the National Institute for Occupational Safety and Health mentions several studies that focused on the effects of working 12-hour shifts. These studies reported that the 9th to the 12th hours of work were associated with decreases in employee alertness, increases in employee fatigue, reduced cognitive functioning and declines in task/operational vigilance, as well as an increased rate of injury (National Institute for Occupational Safety and Health, 2004). Dembe, Erickson, Delbos, and Banks (2005) also concur with the fact that working in jobs that routinely demand extended hours, overtime hours, or extended working schedules increases the risk for worker injury and illness. Fatigue and stress caused by overtime schedules and excessive working hours (>=12 hours per
day or 60 hours per week) has the greatest relative risk of occupational injury or illness (Dembe, Erickson, Delbos, & Banks, 2005). In summary, it could be said that duration is an extremely common and is potentially an oft overlooked yet incredibly important risk factor.

**Vibration.** In the simplest of terms, vibration could be thought of as slight, quick and repeated movements. Generally, human exposure to vibration in the workplace consists of physical contact with objects, tools, or machines which are undergoing a series of rapid high-energy cyclical motions. Upon physical contact with a vibrating surface, vibration energy is transferred to and radiated through the soft tissues of the hands and arms, feet, or the entire bodies of workers. Griffen (2011) states that although many individuals are regularly subject to forces of vibration in the workplace, the ramifications of being exposed to such rapid oscillatory motions are not yet completely understood. Dul and Weerdmeester (1993) suggest there are two distinct categories of vibration to be understood in relation to ergonomics, where one affects the entire body while the other impacts only a single part of the body. During whole body vibration, the entire body is being subjected to vibratory oscillations which generally emanate from the floor that an individual is standing on and travel up through the feet to the remainder of the body (Dul & Weerdmeester, 1993). Additionally, the vibration could be emanating from a chair that an individual is sitting upon wherein the vibration is transferred through the lower extremities and back towards the rest of the body (Dul & Weerdmeester, 1993). Conversely, hand-arm type vibration would singularly affect only the upper extremities such as the fingers, palms, or the whole arm (Dul & Weerdmeester, 1993). Hand-held power tools are often a major contributor to the risks of hand-arm vibration (Dul & Weerdmeester, 1993). Dul and Weerdmeester (1993) identify three variables that are central to evaluating vibrational risks which include the severity of the vibration, the rate of vibration, and the amount of time that a person is exposed to the
source of the vibration. From a vibration exposure consequence standpoint, there are several possible negative short-term and long-term outcomes. Bodily exposure to vibration is known to cause discomfort in instances of certain frequencies, magnitudes, and exposure times (Dul & Weerdmeester, 1993). As for a long-term vibration-induced chronic condition, vibration syndrome is described as a decrease of sensation or touch combined with paleness in the fingers which makes the individual less able to feel the effects of heat, cold, and pain (Karwowski, 1992). The first occasion of observed blanching or paleness generally transpires a considerable amount of time after the individual is initially subjected to vibration (Griffin, 2011). Vibration syndrome often causes workers to experience symptoms such as pins and needles, a loss of sensation, graying of the skin (cyanosis), and in rare instances, the occurrence of gangrene (Griffin, 2011).

**Static loading.** It should be noted that even proper stationary and immobile postural positions can be detrimental if such are assumed and maintained for extended periods of time that the working muscles of the body accumulate tension, and thus experience diminished blood circulation (Tayyari & Smith, 1997). Karwowski (1992) notes that significant amounts of occupationally-related static efforts or loading positions become extremely fatiguing to the bodies of workers, and thus such postural working positions cannot be held for extended periods of time. Static exertions or static postures could fundamentally be described as constant and protracted muscular contractions (Grandjean, 1980). Additionally, it must be understood that throughout periods of static postural exertions the muscles are compelled to contract and not permitted to extend (Grandjean, 1980). Grandjean (1980) explains what is happening inside the human body in a static loading position by delving into an elementary description of the internal workings of muscle tissue during a static loading event. Accordingly, throughout static postural
exertions, blood vessels become constricted from interior forces upon the muscular tissues thereby restricting the bloodstream that would normally be flowing through those same muscular tissues (Grandjean, 1980). During this time, the muscle tissues carrying out the demanding static-based task are not receiving the nourishing glucose and oxygen to which it is normally accustomed to receiving from the circulatory system, thus the deprived muscle tissue must continue the forceful exertion and sustain itself with its rapidly depleting internal energy resources (Grandjean, 1980). Grandjean (1980) outlines the consequences of this action and the loss of blood flow by concluding that the most critical and detrimental drawback of assuming and holding a static postural position is that the waste products normally evacuated from the muscle tissues by the process of normal and regular bloodflow are no longer being expelled and are thereby left to build up within the muscle tissues.

Normally as the blood flows, it provides fresh nutrients to the muscle and shuttles away the blood that has already been used. However, under the restricted blood flow conditions of static loading, the situation is the complete opposite because the waste products that would normally depart from the muscle tissue are allowed to accrue and culminate in severe pain and exhaustion of the muscle tissue (Grandjean, 1980). The results of excessive static loading are recognized as a sensation of extreme discomfort and sore aching muscles. Consequently, it is for these reasons that the human body cannot tolerate or endure static muscular contractions for extended periods of time because the extreme discomfort or pain will eventually coerce an individual to terminate the static muscular postures and exertions (Grandjean, 1980).

The aforementioned analysis and detailed interpretation of a static loading event concurs with the work of Alexander and Pulat (1985). Alexander and Pulat (1985) explain that as a consequence of muscular effort, lactic acid is generated by the muscle tissues and an excessive
amount of lactic acid collects and builds up inside the muscle tissue over a short period of time. Alexander and Pulat (1985) make this process easy to understand by concluding that pain is induced as a consequence of the muscle tissues developing an overwhelmingly acidic pH level (Alexander & Pulat, 1985). During a static loading activity, it would be unadvisable to bear the weight of heavy tools or objects found in the workplace. This is because according to Alexander and Pulat (1985), if the load imposed by static postures is further augmented by additional weight from external sources, the increased weight and stress compounded by the static forces at work will hasten the process by which the muscle tissue would begin to rapidly exhaust its already limited supply of stored energy. (Alexander & Pulat, 1985). As this biological process continues inside the muscles being placed under a heavy static load, the amount of lactic acid and therefore the overall level of acidity inside the muscle will be markedly/significantly increased (Alexander & Pulat, 1985). Finally, this process of muscle fuel exhaustion and accumulated lactic acid leading to overall acidity of the muscle tissues will result in pain and soreness of the muscles involved with the static working posture (Alexander & Pulat, 1985).

According to the European Agency for Safety and Health at Work (2013), awkward and uncomfortable static postures need to be examined and taken under consideration, because these types of postures in the wind turbine industry are linked to the development of musculoskeletal disorders.

**Temperature extremes.** The human body is amazingly capable of environmental-related adaptation, but it likely has certain limits. According to Lehto and Buck (2008), the occupational environments and atmospheric conditions that individuals are surrounded by and exposed to can differ significantly. Additionally, the human body is extraordinarily capable of carrying out work in a satisfactory manner when subjected to variety of atmospheric and
environmental settings and circumstances (Lehto & Buck, 2008). This ability to work in under the strain of various environmental and atmospheric conditions is due to a process of adaption by the human body and during this adaptive process, the body must thermoregulate itself to maintain an optimal core temperature. The most crucial and central concern is that the unconsciously intelligent human body of a worker automatically attempts to adapt itself to a diverse array of both thermal and environmental conditions in order to maintain a critically regulated and vitally imperative core body temperature inside an incredibly limited range of only 36 to 37 degrees Celsius (°C) or 96.8 to 98.6 degrees Fahrenheit (°F), respectively (Lehto & Buck, 2008).

Numerous individuals would likely know the feeling of being/working outdoors/outside in sub-optimal conditions such as freezing cold where certain body parts (most notably the hands) may struggle to perform even the simplest of tasks while working unprotected from the cold. Therefore, it should be no surprise that working in cold temperatures can potentially induce or contribute to work related musculoskeletal disorders. According to Cohen et al., (1997), cold temperatures are among the most significant risk factors of environmental workplace conditions which are capable of affecting the incidence rate and inducing the overall occurrence, severity, and total consequences of work-related musculoskeletal disorders.

Although the human body seems to be incredibly adaptable to various environments, it is likely to be susceptible to what might be considered subtle or minor changes in core temperature. According to Lehto & Buck (2008), from an occupational safety and health perspective, deviations in core body temperatures of less than 1 °C are generally viewed as the acceptable limit. Deviations of an individual’s internal core body temperature of greater than 1 °C can result in severe, life-threatening, or even fatal outcomes (Lehto & Buck, 2008). It should be
noted that critical changes in vitally important core body temperature do not simply occur from workplace exposure to environmental cold sources, but could also stem from exposure to environmental heat sources.

Thermal heat-related conditions are usually described as heat stress and heat strain. According to Bernard (2011), occupationally-related heat stress on the human body is essentially caused by the combined collective effects of the clothing and safety equipment donned by workers in addition to the all-important matters of climatic conditions in the working environment. Additionally, the particular metabolic demands of the individual may become a factor (Bernard, 2011). All of these effects may be operating in disharmony and working against the individual during exposures to sub-optimal environmental working conditions (Bernard, 2011). The major indicators and symptoms which are evident during periods of heat stress upon the human body include marked elevation in core body temperature and fluctuations in heart rate as well as obvious outward indicators such as profuse sweating (Bernard, 2011). The temperature measurement of greatest concern for workers is generally related to their core body temperatures. The reason for this is that deep core body temperature measurements are the principal and critical measure by which occupationally related heat stress and heat strain are assessed and evaluated (Bernard, 2011). Although the prevention of occupational fatalities related to heat strain are imperative, heat stress and heat strain can instigate or trigger other occupational heat-related disorders as well as initiate or produce severe occupational heat exposure related injuries (Bernard, 2011). Further, as Bridger (2009) importantly points out, certain higher than normal body core temperatures may have alarmingly perilous results for workers. According to Bridger (2009) deep core body temperatures exceeding 39.5 °C (103.1 °F) will be immobilizing and incapacitating to workers while core body temperatures that exceed
42 °C (107.6 °F) regularly result in a fatality. According to the European Agency for Safety and Health at Work (2013), hot environmental temperatures can be an issue for wind turbine technicians, especially when they are climbing the tower and working in the nacelle in the summer heat.

Besides extreme heat, concerns related to cold temperatures within the work environment may have a significant impact or effect on both the occurrence and incidence rate as well as the degrees of severity for work related musculoskeletal disorders (Cohen et al., 1997). As Bridger (2009) emphasizes, WMSDs are definitely not the only concern when it comes to cold stress. It should be noted that a core body temperature of 35 °C (95 °F) is at the bottom of the range of acceptable body temperature measurements and that a core body temperature of only 33 °C (91.4 °F) is the level at which cardiac disturbances are generally observed (Bridger, 2009). Bridger (2009) also states that additional reductions in core body temperature are tremendously hazardous and that a deep core temperature of 25 °C (77 °F) will almost certainly have fatal consequences. Furthermore, studies performed by the Eastman Kodak Company (2004) have concluded that cold stress is an obstacle which presents the dual hazards of both hypothermia and localized cooling of the various musculoskeletal tissues. Thus, both hazards should be taken into account in the decision-making process regarding when employees have entered into or exceeded the occupational health risk zone for cold stress (Eastman Kodak Company, 2004). It may also come as a surprise to learn that hypothermia can transpire at what would normally be considered fairly comfortable ambient environmental temperatures, but according to Eastman Kodak Company (2004), air temperatures of 10 °C or 50 °F may also cause of hypothermia. For these reasons, an ambient air temperature measurement of 10 °C or 50 °F is therefore a sensible
and judicious threshold to be used as an indicator or warning sign for the potential occupationally related occurrence of cold stress (Eastman Kodak Company, 2004).

**Contact stress.** One of the most common forms of contact stress occurs during the improper use of an appendage as an inappropriate substitute in a workplace situation where a tool should be utilized in order to perform a job. For instance, a common unfortunate occurrence in the workplace is the practice of employees utilizing their hands, knees, or any part of the body for forceful striking motions, much in the same way that someone might wield a hammer or another type of blunt instrument to hit or move an object into place (Eastman Kodak Company, 2004). Another common type of contact stress in the workplace might include carrying and moving objects with sharp square edges or bulky and awkward items with one or more protruding ridges that digs into the soft tissues of the hand while being lifted and carried (Eastman Kodak Company, 2004). Other examples of this same phenomenon would also include items that possess carrying handles or similar grasping and lifting points which are not comfortable when held in the hands because of the object’s size or shape. Discomfort could be caused by narrow edges or sharp angles that have a tendency to dig into the soft tissues of the hands and arms when being lifted and carried (Eastman Kodak Company, 2004). This uncomfortable pressure generally comes from purposeful, incidental, or accidental interactions with tools, objects, and surfaces in the workplace. At times these types of interactions between the soft tissues of human workers and their working environments may well result in elevated levels of contact stress which generate excessive compression forces over a limited area of the body and thus impede nerve conduction and blood circulation (Grant, 2011). Further, Grant (2011) points out that these workplace interactions between employees and their physical environment should be monitored as part of a potential ergonomic assessment. Specific areas
and regions of contact between the bodies of workers and the work surfaces or tools utilized in the work zone should be recognized, characterized, and documented (Grant, 2011). The reason these ergonomic concerns are warranted is that frequent or recurrent contact and interaction with hard objects and sharp surfaces in the workplace may generate excessive compressive forces on the soft tissues of the body which can both impede nerve function and reduce the vital flow of blood to bodily tissues (Cohen et al., 1997).

In summary, the mitigation of occupationally related ergonomic risk factors which pose an assorted variety of physical assaults on the human body is the definitive objective of ergonomics (Kearney, 2008). Now that the risk factors which may lead to musculoskeletal disorders (MSDs) have been explored, an explanation will take place as to how these risk factors may be identified. This can be accomplished with the utilization of various helpful ergonomic assessment tools, which the subject of the next section.

**Ergonomic Assessment Tools used to Identify Risk Factors**

There are numerous assessment tools that may be utilized to readily identify multiple types of ergonomic risk factors in the workplace. Accordingly, several relevant ergonomic assessment tools will be summarized and described. Explanations will be provided as to the types of tools and how such are utilized in practice. This will be the subject of the following literature review section.

**An explanation of ergonomic assessment tools.** The subject of ergonomics is extensive and wide-ranging, but there are two main classifications and categories of ergonomic assessment tools that cover and extend across the entire disciplinary field of ergonomics. The two main groupings consist of ergonomic checklists, questionnaires, or worksheets, as well as ergonomic task analysis exercises (Bridger, 2018). Fundamentally, checklists are utilized to ensure that
every part of a job is analyzed, while a task analysis involves picking apart each aspect of a job to be assessed and thoroughly analyzing the actual job duties one by one (Bridger, 2018; Cohen et al., 1997). Risk factor checklists can be a useful means of identifying possible musculoskeletal disorders causes and can be designed to concentrate on the specific qualities of different industries and additionally, can be improved by examining and studying the specific occupation to be assessed (Armstrong & Lifshitz, 1987). Additionally, according to Stanton and Young (1999), the use of questionnaires is a universally recognized method of collecting data in order to perform ergonomic research. It should also be noted that the process of a task analysis is not set in stone and is therefore reasonably flexible with common elements that can be adapted to specific activities or occupational settings (Cohen et al., 1997).

An assessment might begin by acquiring a thoroughly written account of the position to be analyzed (Cohen et al., 1997). Throughout the analysis of a given activity, the job tasks might be separated or divided into a variety of discrete and distinct operational job tasks or actions. Each job task would then be thoroughly analyzed to establish the ergonomic risk factors that are specifically related to the job task or those specific ergonomic risk factors that are present during the occurrence of the job task (Cohen et al., 1997). Importantly, workers and operators are frequently interviewed before, during, or after the completion of certain job tasks in order to establish whether the method by which the task is accomplished has a tendency to change over a period of time (Cohen et al., 1997). Additionally, the performance of job tasks may also change depending on which employee is assigned to complete the specific task. The analysis and information gathering process remains flexible to properly assess the individual and the process being observed. Occasionally, risk factors are evaluated separately in terms of consequence and
severity, the amount of times an ergonomically significant action is repeated during a given job task, and the usual duration of exposure to the risk factor (Cohen et al., 1997).

Cohen et al., (1997) identifies the three main areas of concern to be assessed for most occupational positions. The first of these three critical areas for evaluation consist of the devices, implements, apparatus, and machinery, as well as the supplies, resources, and constituent materials utilized to accomplish tasks and complete the job (Cohen et al., 1997). The second of these three critical areas of evaluation consists of a thorough examination and analysis of the employee work area including the layout of the workstation and the measurements of worksurfaces and/or the physical environment with which the employee is constantly interacting during the performance of tasks (Cohen et al., 1997). The third critical area of task evaluation consists of analyzing and assessing physical work demands and evaluating the structural or managerial climate in which the work is performed (Cohen et al., 1997). The means to capture almost all of the necessary information to be analyzed would likely include a thorough examination and observation of the employees conducting their assigned tasks, performing video recordings of the employees at work, and taking still pictures of ergonomically significant work postures (Cohen et al., 1997). It would also include taking measurements of employee workstations, establishing or verifying the surface characteristics of workstations and tools or equipment with which the employee interacts as well as determining the degree to which employees are exposed to vibration, temperature extremes, and any other items of ergonomic concern (Cohen et al., 1997). These information collection procedures should all be performed at the site where the task is performed (Cohen et al., 1997). Other data collection procedures that can be implemented before and after the initial videotaping, recording of measurements, and data collection may include the use of several techniques and practices. According to Cohen et al.,
(1997), these techniques might include the use of employee interviews, survey questionnaires, and the use of subjective rating systems to ascertain and establish the degree to which employees perceive their level of exertion while participating in their normal workplace tasks.

**Examples of ergonomic assessment tools.** Examples of ergonomic assessment tools include the Ergonomic Assessment Checklist, Hazard Checklist, and Work Analysis Checklist. There are a number of useful overall observational instruments available which can be used to assess the worksite, obvious hazards, and potential problem areas for further analysis (National Institute for Occupational Safety and Health, 2018; Occupational Safety and Health Administration, 2018; Pulat, 1992).

**Videotaping employees performing work duties.** One common practice is to make video recordings of occupational tasks in order to perform a comprehensive ergonomic examination and analysis at a later date (Cochran, Stentz, Stonecipher, & Hallbeck, 1999). This is a particularly valuable means of providing detailed and verifiable documentary evidence which allows the thorough assessment of occupationally-related ergonomic musculoskeletal disorder risk factors (Cochran, Stentz, Stonecipher, & Hallbeck, 1999). The practice of videotaping an employee’s task performance also allows for a time measurement to be taken regarding tasks, procedures, and movements which are associated with the task (National Institute for Occupational Safety and Health, 2018; Ortiz & Gleaves, 1991).

Grant (2011) mentions several noteworthy tips to recording employee work activities on video. For instance, it may be necessary to videotape the employee from various positions or angles in order to obtain usable material which documents all the relevant working postures of ergonomic concern (Grant, 2011). Further, if more than one employee performs identical job tasks, it may be advisable to make video recordings of at least two to three of these individuals in
order to document and ascertain the potential differences in job task techniques and approaches taken by different employees who perform similar essential occupational functions (Grant, 2011). Quesada (1999) makes mention of another useful tactic in the ergonomic videotaping process which involves the use of physical markers placed on the moving surfaces and main joints of the body. The body surface markers which are placed on the subject of the video recording assist the videographer in identifying the locations of various important joints of the human body as it moves during the recording, thus aiding in the identification of certain postures and movements of the individual during playback of the ergonomic assessment video (Quesada, 1999).

_Goniometer._ A goniometer is a tool used to measure the angular degrees of postural deviation from the norm. Pausing the replay of the videotape allows the researcher to align the manual goniometer with the postures pictured on or near the video screen (Konz, 1999). A goniometer is comparable to a protractor with elongated arms which is used in measuring the approximate angles of bodily joints and motions (WorkSafeBC, 2003). This instrument is useful in assisting ergonomists to assess and prevent the occurrence of musculoskeletal disorders because of its ability to help the ergonomist accurately and immediately measure the adverse postural positions and joint angles of the worker while the analyst uses views photographs and video of workplace activities and uses the goniometer to assess employee joint angles and postures (WorkSafeBC, 2003). Workplace designs, employee reach issues, and range of motion issues may also be evaluated while using a goniometer (WorkSafeBC, 2003). Use of a goniometer can help an ergonomist perform more reliable assessments and evaluations of employee joint angles and postures which may also provide an improved and more complete list of recommendations to mitigate observable ergonomic issues (WorkSafeBC, 2003). It can also
be used before and after a workplace or a task has been redesigned in order to assess the success of the redesign in relation to improved employee postures and joint angles (WorkSafeBC, 2003).

**Ergonomics Task Analysis Worksheet.** The Ergonomics Task Analysis Worksheet is a thorough and highly regarded instrument to identify risk factors in the workplace and was designed by the Great American Insurance Company. In use, the Ergonomics Task Analysis Worksheet functions as a score sheet to rate the severity of multiple different types of ergonomic risk factors encountered in the workplace. It provides examples of both ideal and adverse postures. It also provides examples of ideal and/or adverse work situations including repetition rates, exposure to vibration, lifting and materials handling, employee reach concerns, force concerns, environmental factors, static loading, contact stress, and also allows the assessor to separately and independently score each visible risk factor that occurs in a given workplace activity (Great American Insurance Company, 2004). It is a useful tool to ergonomically evaluate risk factors in-person or after making video recordings and taking photographs of the tasks to be assessed, which allows easier completion of a comprehensive analysis of the workplace activity as well as providing progressive recommendations. It also contains summary worksheet pages which help to bring the analysis together onto a straightforward chart which allows for scoring of the assessment and leads to a plan of action with potentially helpful recommendations for changes in the workplace (Great American Insurance Company, 2004). A reference copy of the Great American Insurance Company Ergonomics Task Analysis Worksheet can be found under Appendix A of this paper.

**Employee Symptom Survey.** The Employee Symptom Survey is an assessment tool completed by a willing employee who is guaranteed confidentiality and anonymity with regard to their honest feedback of MSD symptoms and risk factors experienced due to work and
working conditions (University of Wisconsin-Madison, 2018; Occupational Safety and Health Administration, 2018). Straker (1999) discusses and reviews tools for assessing and evaluating physical body discomfort of workers which could be used to assess the ergonomic situation between the worker and their workplace. Multiple decades of research in the areas of occupationally related pain and distress as well as applied knowledge and understanding by practitioners of ergonomics has culminated in the creation of user-friendly, precise, and scientifically legitimate tools for assessing pain and discomfort in the workplace caused by unsatisfactory ergonomic situations (Straker, 1999).

The employee symptom survey is utilized by delivering the survey to an employee after providing basic instructions (UW-Madison Health Services, 2018). The employee then completes the form by answering specific questions relating to problems of pain or discomfort in specific areas of their bodies as well as the details surrounding the problem including; care should be taken to begin with the identification of symptoms, length of time symptoms have been experienced, recurrence of symptoms, lost time from work, medical treatment for the problem, as well as identifying probable causation (UW-Madison Health Services, 2018). The form also includes an anatomical drawing of a human body which allows the employee to circle, shade-in, or otherwise indicate what areas of the body are bothering them (UW-Madison Health Services, 2018). Employees also have the opportunity to indicate by check-marking words and/or items that are indicative of the symptom or area of the body that is bothering them (UW-Madison Health Services, 2018). The survey also provides a list of terms which assist the employees to describe the degree of pain and classify the symptoms associated with the discomfort degree of pain and discomfort (UW-Madison Health Services, 2018). An example of the symptom survey can be found under Appendix B of the paper.
**Employee interview.** A confidential employee interview could be conducted at the worksite, through a computer or over the telephone and a guarantee of anonymity would be a prerequisite of employee participation in such proceedings. A set list of standard questions pertaining to the job, its tasks, and risk factors is asked of each participant (Ortiz & Gleaves, 1991). Beyond the use of pre-set lists of predetermined questions, casual and confidential interviews or discussions with employees and their supervisors could generate additional valuable information that may be utilized to produce a more knowledgeable and informed analysis of the ergonomic situation (Grant, 2011). Employees who execute certain job tasks every working day may be the most valuable source of information related to the particular aspects and fundamental features of the job which could present or contribute to ergonomic hazards (Grant, 2011). During an ergonomic job analysis, an interviewer could ask numerous questions in an employee interview, however it would be most advantageous to ask questions that directly relate to the probable occurrence of workplace musculoskeletal disorders. A typical inquiry may include questions regarding the employee’s daily job duties and how they perform the job on a step-by-step basis. It may also include questions related to the specific physical stressors of the workplace as well as the potential ergonomic risk factors that they are exposed to during their job tasks and the degree to which they are experiencing MSD symptoms as a probable or likely result of certain work activities.

Radwin, Yen, Beebe, and Webster (2011), make note of various ergonomic assessments and electronic, or technology-driven measurement tools. For example, accelerometers may be used to measure vibration on the human body, on the tools, or work station. Heart rates may be measured using cardiotachometers and electrodes. The metabolic rates of workers may also be estimated through the performance of a metabolic rate analysis calculation which is used to
estimate the exertion or overexertion of workers as they perform certain tasks. Further, transducers and piezoelectric sensors may be utilized to record an assortment of ergonomic force-based measurements. Less complicated means of ergonomic force measurement may include the use of mechanically-based force measurement tools and instrumentation (Radwin & Yen, 1999). This could include instrumentation such as a basic ergonomic force measurement gauge, a hand-held dynamometer or a hydraulic pinch grip gauge. Basic and straightforward industrial ergonomic assessment devices similar to a spring scale may be utilized in multiple different applications or situations to approximate and evaluate the forces involved with occupational tasks and actions of employees as well as to estimate the weight of loads that employees may be asked to carry during the performance of their jobs. (Radwin & Yen, 1999).

**Anthropometrics**

According to Goetsch (2019), anthropometry is the scientific study of human forms, functions, physiques, and body sizes. Essentially, anthropometric measurements can be utilized to improve the interactions between employees and equipment, tools, vehicles, and workstations, as well as the personal protective equipment that they wear as a last line of defense against ongoing and/or imminent workplace hazards (Goetsch, 2019). Given that ergonomics tends to involve fitting the task to the employee, the use of anthropometric measurements can perform a crucial role in recognizing, isolating, and categorizing ergonomically based complications and ergonomic hazards in the work environment (Goetsch, 2019). According to McLeod (1995), anthropometrics can be described as an ergonomically relevant and apposite discipline that is dedicated to the measuring the dimensions and proportions of human bodies. According to Pulat (1992), the science of anthropometric measurement involves calculating, assessing, and quantifying the linear dimensions of bodily forms, reaching distances, joint to joint and point to
point lengths, as well as the weights and volumes of human figures. Illustrative examples of these types of measurements could include bodily structure, circumference, width, length (stature height), size, and structure as well as more specific measurements such as seated eye height, standing shoulder height, standing overhead reach distance, forward reach, and standing elbow height (Goetsch, 2019). Anthropometric measurements could also consist of specific point-to-point bodily measurements such as arm span length (fingertip-to-fingertip or palm-to-palm with arms stretched out laterally at the sides), or other various distances such as ankle-to-knee or elbow-to-wrist measurements (Goetsch, 2019). The entirety of these types of anthropometric measurements can provide a highly useful and precious resource of supporting information which may aid in the design of superior products or the redesign of manufacturing processes, tasks, and working procedures in order to eliminate or at the very least minimize ergonomic hazards (Goetsch, 2019). McLeod (1995) provides supportive testimonial that the application of anthropometric information can be applied in order to aid in the creation of ergonomically improved environments and working situations suitable for the design of both residential and business settings, including all of the places that people work, cook, dine, recreate, rest, and recuperate. Resources such as the *Handbook of Ergonomic and Human Factors Tables* by Jon Weimer (1993) as well as The Eastman Kodak Company (2004) provide many useful examples of anthropometric data tables which could be utilized by engineers seeking to create designs that are superbly suitable for human use. According to Weimer (1993) and Eastman Kodak Company (2004), anthropometric data gathered from research within the U.S. military on the human form has been utilized for numerous years to aid in the design of modern workstations, equipment, assembly lines, products, tools, materials, and industrial equipment. In fact, NASA has used anthropometric data in the space program to successfully design ships and shuttles for
the purpose of accommodating the occupants of spacecraft and other equipment which humans interact with or inhabit (Eastman Kodak Company (2004). Examples of anthropometric data tables taken from Eastman Kodak Company (2004), can be found within Appendix C of the paper.

According to Grandjean (1988), when anthropometric data is utilized in the designs of workplace settings and equipment that employees interact with, the designs usually attempt to cater to either 90 or 95 percent of the population. This means that in the design of an object which endeavors to cater to the height of 95 percent of the working population, an attempt will not be made to accommodate the tallest 2.5% and shortest 2.5% of workers (Grandjean, 1988). According to Ostrom (1993), when work environments are being designed, care must be taken to allow for workplace adjustments in order to accommodate a wide range of employees and provide them with a safe place of employment. Usually, the scope of body sizes which it is necessary to accommodate consists of the range from the 5th to the 95th percentiles (Ostrom, 1993). This will accommodate 90 percent of the population to be catered towards, thus guaranteeing that the majority of workers can utilize the workplace or object without major difficulties (Ostrom, 1993). In this scenario, where 90% of the working population is being catered to, those individuals left at the upper and lower 5% of the spectrum will need to have special designs and accommodations purposely made to serve their specific and different anatomical conditions (Ostrom, 1993). As for problems related to anthropometry, Pulat (1992) essentially states that ergonomic problems with a basis in anthropometry are essentially associated with the dimensional conflict between the bodies of workers and the functional geometrical spaces with which they must interact in order to perform certain jobs. According to Pulat (1992), these problems evidently manifest themselves as a design deficiency which creates
a mismatch between the bodies of human workers and the dimensional space of the workplace. The solution to the problem of anthropometric mismatch between the worker and the workplace presents itself as a need for redesigning or modifying the design of the workplace in order to establish a new level of worker-workplace compatibility (Pulat, 1992).

**Ergonomic Hazard Controls**

The four key elements of a workplace musculoskeletal disorder control program are identification of emerging employee health problems, evaluation of occupational risk factors, application of ergonomic control measures, and finally, further assessment of the chosen controls which were placed into action (Silverstein, 1987). When it comes ergonomic control measures there is an extensively recognized hierarchy of ergonomic hazard controls that consist of three primary categories which are ranked in order from most to least effective (Cohen et al., 1997). The three-tiered hierarchy consists of engineering controls, administrative controls, and the utilization of personal protective equipment, listed respective to the order of effectiveness, from highest to lowest (Cohen et al., 1997). According to Cohen et al., (1997) administrative controls commonly entail those work practices, strategies, and policies which are directed and utilized by management in an effort to aid in the prevention or bring about a reduction of employee exposure to ergonomic risk factors in the workplace. By and large, administrative controls are the second most effective form of ergonomic hazard controls and generally consist of changes to occupational rules, work organization, timing, regimens, instructions, guidelines, and work procedures. An example of a general administrative control would include the well-regimented scheduling of regular and consistent work rest breaks for each employee who performs a specific job function or task over a period of time (Cohen et al., 1997). Further examples of administrative controls would include the provision of additional work rest breaks as necessary.
for those individuals performing heavy and/or exhausting tasks as well as those individuals laboring under less than ideal environmental conditions which tend to increase worker fatigue (Cohen et al., 1997). Additional examples of administrative controls would include items such as altering and regulating the pace of work in order to cut down on excessive repetitive motions as well as rotating employees through a series of job tasks, with each task placing differing physical demands on the body in order to reduce the stress placed on any one area of the bodies of workers and to spread out the amount of physical stress so that it is not concentrated on certain joints and limbs or not centered on a singular area within of the musculoskeletal system (Cohen et al., 1997). Other examples of administrative controls would include a reduction in the length of work shifts and reducing overtime hours; giving the employees more control over how to perform the task in the most ergonomically beneficial way possible (Cohen et al., 1997).

Supplementary administrative controls would include the delivery of educational materials and instruction on techniques which might aid in the reduction of workplace stress and strain during the performance of normal and non-routine tasks; as well as providing awareness and vigilance training for workers so that they can more easily recognize the ergonomic stressors of the job as well as the commonly associated risk factors for work related musculoskeletal disorders (Cohen et al., 1997). Administrative controls may also include practices such as the regimented rotation of employees through those jobs that are deemed to be physically exhausting so that the workload is shared and that no individual worker is consistently responsible for performing the most exhausting of job duties while other workers are tasked with the performance of the lighter less fatiguing work (Cohen et al., 1997). These administrative controls are implemented in order to limit the probable detrimental and injurious impacts upon employees that are incurred by overexposure to physical job stressors (Putz-Anderson, 1988).
Putz-Anderson (1988) outlines the basic difference between engineering and administrative controls. Engineering controls tend to focus on the job tasks or the occupational environment while administrative controls emphasize the placement of management-related measures on the workforce as a whole or upon individual employees as necessary (Putz-Anderson, 1988). Engineering controls being the most effective types of ergonomic hazard controls to prevent work related musculoskeletal disorders consist of three general sub-categories (Cohen et al., 1997). Generally, these include changes to the overall design and arrangement of the work environment, changes in the selection and utilization of tools or devices operated by workers, and changes in methodology for conducting the overall job as well as specific occupational tasks (Cohen et al., 1997). Additionally, engineering controls should take into consideration the overall capabilities as well as the inherent human inadequacies and limitations of the available labor force (Cohen et al., 1997). Cohen et al., (1997) provides numerous useful examples of engineering controls. The condensed version of engineering controls suggested by Cohen et al., (1997) essentially includes various significant and non-significant changes to the job, the tools used, or the work environment which essentially make the work less physically stressful with fewer negative impacts upon the bodies of workers.

A general summary of engineering-based examples includes changes in the way that all types of objects and materials are moved, transported, and manipulated during the work process; changes to the work process, the task sequence, or to the types of objects and materials used in the work in order to reduce exposure to ergonomic stressors (Cohen et al., 1997). Also included are changes in the adjustability of the work environment to promote ergonomically acceptable postures and accommodate individual workers of various sizes or abilities; as well as changes in the orientation, position, or location of various objects, materials, functions, and features in order
to improve access and provide a reduction in stressors such as the forces required or the functional human reach necessary to perform a given task (Cohen et al., 1997). Further, engineering controls should provide an excellent match between the working population and the demands of the job so that no unwarranted or excessive physical strains and ergonomic stressors are placed on individual workers (Cohen et al., 1997). Hamrick (2006) offers an appropriate summary of engineering controls by essentially stating that all available evidence demonstrates a conclusive point related to the reduction of musculoskeletal disorders. Hamrick’s conclusion essentially states that a reduction in employee exposure to bio-mechanical stressors or physio-mechanical forces is a necessary condition which must take place in order to diminish the presence of work-related musculoskeletal disorders (Hamrick, 2006). Engineering controls which eliminate or at least substantially reduce the ergonomic risk factors for musculoskeletal disorders are an excellent strategy for those who seek to reduce work-related musculoskeletal disorders (Hamrick, 2006). In summary, Hamrick (2006) also mentions another important final point which may be taken as a warning against the careless implementation of engineering controls without the use of supportive systems. Implementing several engineering controls cannot be expected to abate all workplace musculoskeletal disorders or ergonomic issues all at once and it may take time with follow-up, worker feedback, and further revision to become a fully operational corrective system (Hamrick, 2006). Further, engineering controls should not be implemented alone, that is, without supplementary factors such as organizational encouragement and structural/institutional support (Hamrick, 2006). According to Hamrick (2006), important elements such as encouraging employee input and promoting user buy-in as well as the backing and endorsement of top management personnel are necessary conditions of the successful
implementation of engineering controls with the goal of reducing work related musculoskeletal disorders to the furthest extent possible.

With regard to personal protective equipment (PPE), there is a valid question as to whether such are even a true hazard control or whether this approach should qualify as a hazard control (Cohen et al., 1997). Even though PPE is typically listed at the bottom of any hierarchy of occupational hazard controls and is mentioned in Cohen et al., (1997), it is actually mentioned as less of an actual remedy to any occupational safety and health problem and more of a final resort to fall back upon in an emergency and/or a critical situation. According to Cohen et al., (1997), PPE is essentially a final contingency plan to be depended upon as a solution to a problem only after all other control options have been truthfully attempted, honestly implemented, and have failed to deliver a viable/workable solution or have been found to be infeasible. Infeasible options mean certain approaches which are impossible to implement in the workplace for sound factual reasons and not just for the sake of monetary and financial reasons or to save money at the expense of employee health.

**Summary of the Literature Review**

This literature review was initiated with a description and definition of ergonomics. A brief history and background of the field of ergonomics was also provided. The focus and purpose of ergonomics was highlighted through multiple examples. Next, musculoskeletal disorders were defined and explained.

A general overview of common work-related MSDs, relevant MSD symptoms, as well as the causes of MSDs was discussed and explored in detail. Subsequently, the ergonomic risk factors pertaining to work-related MSDs were accounted for and expounded upon thoroughly. Each risk factor (including force, posture, repetition, duration, vibration, static loading,
temperature extremes, and contact stress) was given the appropriate consideration with regard to the ergonomic work situation to be analyzed. A variety of ergonomic assessment tools were explained and multiple common types were listed and detailed. The scientific discipline of anthropometrics was described and explained in relation to MSD concerns. Finally, ergonomic hazard controls were explained in detail.

Regarding the tools and instruments discussed within this chapter, it is anticipated that the most helpful and practical means for performing the assessment and analysis of wind turbine technician ladder climbing activities would include the combined implementation of several different ergonomic assessment tools/techniques discussed within this chapter. Taking physical measurement of the work area and the dimensions within the wind tower as well as the ladder itself could potentially identify whether there is enough space to comfortably access and properly utilize the ladder. Measurements could identify potential hazards, obstructions, or adverse conditions in the immediate area of ladder rungs and stiles which present impediments to the comfortable and efficient ascent and descent of the ladder. Another helpful ergonomic assessment tool that could be utilized would be video and still images of employees ascending and descending the wind turbine ladder in order to capture movements and postures for further observation and analysis with special attention paid to the detection and recognition of potential MSD risk factors. Once the activity is documented with video and photographs, a goniometer would likely be used to identify and substantiate adverse postural positions and joint angles which may contribute to the development of MSDs. Another tool to be used with the captured video footage and still photos would be the Great American Insurance Company’s Task Analysis Worksheet which could aid in the thorough assessment of the ladder climbing activity in relation to the observation and recognition of ergonomic MSD risk factors potentially contributed by the
ladder climbing activity. The Great American Insurance Company’s Task Analysis Worksheet may also be helpful in analyzing overall work situations and would allow for separate and independent scoring of the risk factors within the ladder climbing activity. Yet another tool that would be useful would be employee symptom surveys which would be administered to each employee to help identify areas of discomfort resulting from their work duties. Finally, employee interviews would provide a chance to make important inquiries and gather pertinent information by posing relevant task and MSD related questions as well as asking workers to describe the ladder climbing activity and identify areas of concern.

It is to be noted that during a review of existing literature and research related to MSDs, an absence was observed with regard to published academic works which purported to study the relationship between the onshore wind turbine ladder climbing activity and the development of occupationally related musculoskeletal disorders or musculoskeletal disorder symptoms for maintenance technicians within the onshore wind turbine energy industry.
Chapter III: Methodology

Company XYZ is concerned that maintenance technicians who frequently climb the internal ladders of power generating wind turbine towers throughout their daily work-shift are placed at risk of experiencing upper as well as lower extremity MSDs. Thus, the purpose of this study is to identify the extent to which musculoskeletal disorders may occur among maintenance employees who are required to frequently climb wind power generation towers throughout their daily work-shift. One of the goals of this study is to survey wind turbine power generation maintenance employees to determine the extent that they are experiencing various musculoskeletal disorder symptoms. A second goal of this study is to perform ergonomic assessments of ladder climbing activities among wind turbine maintenance personnel in order to quantify the extent of force, posture, repetition, duration, vibration, and temperature-related risk factors to which the technicians are typically exposed. A third goal of this study is to compare the quantified tower maintenance employee risk factors against commonly-used ergonomic risk assessment tools. This chapter will include a discussion of the subject selection and description of the subjects involved in the study as well as the instrumentation to be utilized during the study. This chapter will also include a discussion of the data collection and data analysis procedures to be used in the study. Finally, this chapter will conclude with a discussion of the study’s limitations.

Subject Selection and Description

The subjects of the study will be technicians who are employed in the wind turbine industry. It is anticipated that a majority of the subjects will be males who range in ages from 20 to 50 years old. Participation in the study will be restricted to subjects over the age of 18, thus
none of the subjects involved in the study will be under the age of legal consent and therefore will be able to participate in the study under their own free will.

All of the subjects involved in the study will have experience climbing wind turbine ladders and will have been trained and/or certified to perform wind turbine maintenance activities. The subjects will be approached via phone, email, and in-person meetings.

Subjects/participants will be selected and will consist of traveling service technicians who either work for or have contact with Company XYZ. Subjects/participants may include inspectors of wind turbine towers, wind turbine site managers, and site-specific wind turbine service technicians, as well as any other readily identifiable parties who regularly climb wind turbine ladders as an essential component of their occupation. Company XYZ has many contacts in the wind turbine maintenance industry and thus will provide the researcher with a list of subjects to be potentially involved in the study. The list of potential subjects will be contacted by the researcher who will explain the anonymous nature and confidentiality of their participation or involvement in the study via phone, email, or in-person. Subjects will also be informed of the nature and timeline (potential time commitment) of the study as well as the potential risks and/or benefits of participating in the study. Subjects will be informed of their right to terminate participation in the study at any time. Subjects will then be asked if they can commit to participating in the study. A subject consent form will be utilized to collect individual signatures from subjects who wish to participate in the study.

Instrumentation

The method of visually documenting the ladder climbing activity will consist of still image and video recording techniques. Manually recorded measurements of objects and dimensions of the work environment will utilize a standard U.S. customary system tape measure
for the purpose of determining lengths and distances in inches and feet. After measurements are collected, certain measurements may be translated into both U.S. customary system units as well as Metric system units in the body of the paper for the purposes of ease-of-use and readability. The second instrumentation to be utilized will consist of still image and video recording cameras to capture and document employee movements and postures during the ladder climbing activities. A manual goniometer will then be utilized to measure body postures taken from pictures and recorded video playback of the climbing activity.

Other forms of instrumentation will include The Great American Insurance Company’s Task Analysis Worksheet for ergonomic assessment (found in Appendix A). Additionally, an Employee Symptom Survey concerning work-related MSD symptoms (found in Appendix B) will be given to study participants along with instructions related to filling-in and completing this survey in the correct and appropriate manner. Finally, conducting employee interviews with a pre-established list of questions would provide an opportunity to generate important data and gather pertinent information by posing relevant task and MSD related questions as well as asking each worker to describe the ladder climbing activity while identifying their individual areas of concern. The subjects will be asked to complete surveys and participate in interviews during their on-duty work time.

Data Collection Procedures

Before initiating the data collection process, maintenance workers will be assured anonymity and privacy when they provide information and respond to questions and surveys as part of the study. The participants will be informed of the private and anonymous nature of the study so they can feel secure that individuals who are not actively conducting or overseeing the study will not be allowed to view or obtain knowledge of their individual answers to survey
questions and assessments. No individuals besides those who are actively conducting the study shall be provided with knowledge of exactly which participants were involved in the study, when or where they participated, and what answers or information they provided when asked for their input.

The data collection procedures will begin with an on-site visit to a wind turbine farm for the purposes of observation and to meet with site personnel. A site visit to a wind turbine farm will include taking measurements of objects in the workplace which involve the ladder climbing activity for an analysis of the work station and the work environment. The site visit would also include taking still photographs and videotaping the wind turbine technicians actually performing ladder climbing and descending activities in order to identify the risk factors that technicians may be exposed to during their daily routines of ascending and descending wind turbine ladders.

The data collection procedure will also involve holding discussions with wind turbine technicians (the subjects of the study) by using a pre-established set of inquiring questions and posing these pertinent questions in a conversational format. Additionally, the technicians will be asked and instructed to complete an individual Employee Symptom Survey. This Employee Symptom Survey will take place near the start of the interview/discussion process. Employee interviews will benefit from the data gathering process by providing specific information taken directly from the wind turbine technicians. Gathering additional information and insight directly from employees in this manner will assist in the evaluation of the ladder climbing activity and possibly provide a better understanding of the potential consequences that ascending/descending ladders has upon the surveyed wind turbine technicians.
All subject-related information will be kept strictly confidential and locked away in a safe place during the study and shall be destroyed upon completion/submission of the study. This would include both paper and electronic forms of data collection materials. Paper materials would be shredded and disposed of appropriately and electron media such as memory cards, jump drives, or flash drives containing pictures and video would be electronically erased and/or reformatted upon completion and submission of the study. Any pictures or video used will be anonymized by blocking out the subject’s face and/or any other identifying features as deemed necessary before being included as a picture (figure) in the body of the paper.

**Data Analysis**

Data regarding the ergonomic video and still picture assessment of the ladder climbing activity will be analyzed to determine the types of risk factors for MSDs and the potential of risk that is present on the human body. During the video playback activity, it will be paused at various stages to take account of the actions being performed by the bodies of workers as they ascend, descend, and stop to rest while climbing the ladder. The manual goniometer will be aligned with the working individual pictured on the playback display screen. Alignment of the goniometer with an image on screen will help to quantify and assess certain bodily angles, positions, and postures of both their upper and lower extremities. Use of the manual goniometer will also help determine certain degrees of spinal and thoracic flexion and/or extension experienced by technicians during this work activity.

The Great American Insurance Company Task Analysis Worksheet (found in Appendix A) will also be used to verify risk factors during the video and still camera image review process. Employee interviews will be used to inquire about MSD related risk factors as it pertains to the wind tower climbing activity. A multi-question Employee Symptom Survey (available in
Appendix B) will be used to inquire about characteristic features and current prevalence of MSD symptoms experienced by the technicians and the resultant WMSD conditions from which they may suffer. The results of the study participants’ responses would then be qualitatively evaluated to assess the risk factors for work-related musculoskeletal disorders related to the wind turbine ladder climbing activities. Survey data will be analyzed by using a computerized spreadsheet to keep track of the answers and tally the total quantity of any prevalent musculoskeletal disorders that may be present as the result of work-related wind turbine tower ladder climbing activities.

Limitations

The limitations of the study exist in three areas. First, the distribution and conveyance of surveys will be limited by the number of wind turbine tower maintenance technicians that can not only participate in the study, but are also actively interested in participating in the study. It may be difficult to find a large pool of potential participants who are truly interested in participating in the study when the immediate and tangible benefits for them to do so may be negligible or unforeseeable. The study may also be limited by the quality of the verbal instructions, directions, or information given to the participants. The findings of the study may also be limited by inadequately utilized or incorrectly completed surveys, questionnaires, and assessment tools. The validity of interpretations and conclusions derived from the data gathered during the study will also potentially be limited by the overall effective value of successful data capture and enthusiastic/unenthusiastic participation from study subjects.

Summary

In order to study the ergonomic factors involved with the ladder climbing activities of maintenance technicians in wind turbine towers, the workspace must be measured, visual
information must be gathered and assessed, and work-related hazards must be identified. Video and still pictures of maintenance technicians performing the essential activity (ascending and descending ladders) will be utilized as part of the overall assessment. Measurements of angles and body positions (postures and movements) will be assessed using a manual goniometer. The Great American Insurance Company Task Analysis Worksheet will be utilized to perform further ergonomic assessment of the work activity. Employee symptom survey and employee interviews will provide additional necessary and insightful data related to MSD symptoms that are reported by the technicians.

A satisfactory analysis of the ladder climbing activity will contribute to an increased understanding of the ergonomic work situation to which wind turbine maintenance technicians are exposed. The study will also make a concerted effort to inquire about those MSD symptoms and conditions that maintenance technicians are currently experiencing as well as those that they have experienced in the past. These WMSD survey results would then be evaluated to assess and identify the types, prevalence, and severity of work-related musculoskeletal disorders experienced by the study participants as a result of performing wind turbine ladder climbing activities.
Chapter IV: Results

According to current data from the Occupational Outlook Handbook from the Bureau of Labor Statistics, there are approximately 5,800 wind turbine technician jobs in the United States (2018). If the trend towards building additional wind turbines in the United States continues on its current path, the number of individuals working in this occupational field is expected to nearly double in size to an estimated 11,400 technician-oriented jobs by the year 2026 (Bureau of Labor Statistics, 2018). Whether the wind turbine technician profession doubles in size during the coming eight years or not, it is likely that occupational safety and ergonomics will be important considerations for each individual who is employed as a wind turbine technician.

The purpose of this study was to identify the extent to which musculoskeletal disorders may occur among wind turbine maintenance technicians who are required to frequently climb wind power generation towers throughout their daily work-shift.

The goals of this study include:

1. Survey wind power generator tower employees to learn about their jobs and work experiences as well as determine the extent to which they may be experiencing various musculoskeletal disorder symptoms.
2. Perform ergonomic assessments of wind power generator tower maintenance personnel ladder climbing activities in order to quantify the extent of force, posture, repetition, duration, and temperature-related risk factors to which employees are typically exposed.
3. Compare the quantified tower maintenance employee risk factors against commonly-used ergonomic risk assessment tools.
The goals of this study were achieved by utilizing various procedures outlined and explained in Chapter III. In order to study the ergonomic factors involved with the ladder climbing activities of maintenance technicians in wind turbine towers, the research began by measuring and assessing the workplace/work environment through the process of visual information gathering and assessment. Following observation of the climbing activity, potential work-related hazards, risks, and adverse conditions were identified. Video and still pictures of maintenance technicians performing the essential activity (ascending and descending wind turbine ladders) was recorded, analyzed, and utilized as part of the overall assessment. During later video playback, measurements of body position angles (postures and movements) were further assessed using a manual goniometer. The Great American Insurance Company Task Analysis Worksheet was utilized to perform further ergonomic assessment of the work activity during playback of the video recordings. A detailed multi-question online survey was written, created, and utilized to assess many different aspects specific to the wind turbine technician occupation. The online survey also included a symptom survey which provided additional necessary and insightful data related to MSD symptoms reported by the technicians. The study made a concerted effort to inquire about the MSD symptoms and conditions that maintenance technicians are currently experiencing as well as those that they have experienced in the past. The survey results were evaluated to assess and identify the types, prevalence, and severity of work-related musculoskeletal disorders experienced by the study participants as a result of performing wind turbine ladder climbing activities. Additional information and insight into the occupational working conditions of wind turbine technicians was gathered during the process of on-site video recording and data collection by the use of a conversational interviews between the researcher and the subjects.
This chapter contains the entire survey, including each individual question and the corresponding analysis of responses given to each question. This is succeeded by a section which contains measurements of the wind turbine ladder and the immediate area surrounding the ladder. The section on measurements is followed by an ergonomic analysis of recorded video climbing data, with findings from the analysis, as well as comments gathered from in-person interviews with the subjects. Finally, the chapter concludes with the utilization of the Great American Insurance Company Task Analysis Worksheet to further assess the recorded video climbing data.

**Presentation of Collected Data**

Three main goals were utilized to conduct this study and data was collected for each.

**Goal #1.** Survey wind power generator tower employees to determine the extent that they are experiencing various musculoskeletal disorder symptoms.

A detailed survey was created and written specific to the working as well as environmental conditions, potential musculoskeletal disorder (MSD) symptoms, and potential ergonomic risk factors in order to capture specific information from a group of online survey respondents who are working as wind turbine maintenance technicians. The survey was converted from a written, paper format to an electronic Qualtrics survey in order to make the survey more widely available to be distributed to potential respondents. Approximately 30 participants responded to the online survey. The electronic survey consisted of nearly 120 questions, although certain questions would only be revealed to the survey respondent upon answering a previous question in a certain manner. For instance, if the respondent answered “Yes” to a certain “Yes” or “No” question, they would automatically skip ahead to the next logical question for them. However, if a survey respondent answered “No” to that same survey
question, then they would be given the next logical question according to their own response.

This was also true for questions related to MSD symptoms so that if a respondent indicated a potential MSD symptom in the knees, he/she would next be served a follow-up question that was specifically related to indicating the MSD symptoms that were being experienced in the knees. Conversely, if a respondent indicated the presence of MSD symptoms in the wrist or lower back only, then he/she would not be served the MSD symptom question related to knee MSD symptoms and would only be served the follow-up questions related to wrist and lower back MSD symptoms. In general, this process created a logical flow throughout the survey that was custom tailored to each respondent according to and directly related to his/her previous responses throughout the MSD identification and discomfort description section of the survey. However, most of the questions throughout the electronic survey were served to all respondents regardless of their answers to previous questions.

<table>
<thead>
<tr>
<th>#</th>
<th>Survey Question</th>
<th>Response and/or Brief Analysis of Survey Responses</th>
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<tbody>
<tr>
<td>1.</td>
<td>Do you currently climb wind turbine ladders as a regular part of your occupational duties or activities (using ladders to ascend and descend wind turbines)?</td>
<td>85.29% of the respondents who answered this question answered in the affirmative, that they do currently climb wind turbine tower ladders.</td>
</tr>
<tr>
<td>2.</td>
<td>Please estimate the number of times per day that you typically climb wind turbine ladders. (Please count each time you ascend up a ladder and then later descend back down that same ladder as one single event).</td>
<td>85.71% of respondents reported climbing more than once per day. 14.29% of respondents reported only one climbing event per day. This could be possible because sometimes wind turbine technicians have job tasks where they might spend the whole day up in the nacelle just trying to repair one turbine. A majority (57.14%) of the respondents who reported climbing more than once per day reported climbing between 3 and 5 times per day (ascending and descending). Also, of those that reported climbing more than once per day, 10.71% reported 6 to 7 climbing events per day.</td>
</tr>
<tr>
<td>3.</td>
<td>Please estimate the total number of times per week</td>
<td>49.99% of respondents indicated that they perform between 10 and 16 climbing events per week (ascending and descending).</td>
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<td>1</td>
<td>that you typically climb wind turbine ladders. (Please count each time you ascend up the ladder and then later descend back down that same ladder as one single event).</td>
<td>The mean was 13.86 climbing events per week, while the mode was 16 climbing events per week.</td>
</tr>
<tr>
<td>4</td>
<td>If you do not currently climb wind turbine ladders as a regular part of your occupational duties, have you regularly used wind turbine in the recent past? (during the previous 2 years).</td>
<td>80% of the respondents who do not currently climb ladders reported doing so in the recent past (within the past two years).</td>
</tr>
<tr>
<td>5</td>
<td>Please estimate how many wind turbine ladders you typically climbed per day during the previous two years of performing this work (please count each time you ascended up a ladder and then later descended back down that same ladder as one single event)</td>
<td>75% of the respondents to the previous question reported that they had 3 to 4 climbing events per day during the previous two years.</td>
</tr>
<tr>
<td>6</td>
<td>Please estimate how many wind turbine ladders you typically climbed per week during the previous two years of performing this work (please count each time you ascended up a ladder and then later descended back down that same ladder as one single event)</td>
<td>75% reported 15 to 18 climbing events per week during the previous two years.</td>
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<tr>
<td>7</td>
<td>Were you trained in how to efficiently ascend and</td>
<td>56.25% responded no, 43.75% indicated yes.</td>
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<td>descend wind turbine ladders?</td>
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<tr>
<td>8.</td>
<td>Were you trained in how to safely ascend and descend wind turbine ladders?</td>
<td>In answer to the question “Were you trained in how to safely ascend and descend wind turbine ladders?”, 87.5% responded Yes, while the remaining 12.5% responded No.</td>
</tr>
<tr>
<td>9.</td>
<td>Do you think that the wind turbine ladder-related training you received was adequate?</td>
<td>85.71% indicated yes, 14.29% responded no.</td>
</tr>
<tr>
<td>10.</td>
<td>If you think that your wind turbine ladder-related training was not adequate, please briefly state how you think wind turbine ladder training could be improved upon.</td>
<td>Responses included statements such as: “extra training time”; “get more experience”; and “train on more different turbines with different scenarios”</td>
</tr>
<tr>
<td>11.</td>
<td>Have you regularly used an alternative means of ascending and descending wind turbines instead of using the ladder (i.e. an elevator or climb assist device)?</td>
<td>78.12% have regularly used an alternative means of ascending and descending wind turbines instead of using the ladder (i.e. an elevator or climb assist device). 21.88% have not used such devices on a regular basis.</td>
</tr>
<tr>
<td>12.</td>
<td>If you could choose only one option, which would you prefer to use as an alternative to climbing wind turbine ladders, an elevator or a climb assist device?</td>
<td>In answer to the question “If you could choose only one option, which would you prefer to use as an alternative to climbing wind turbine ladders, an elevator or a climb assist device?”, 100% of the respondents would prefer a wind turbine elevator.</td>
</tr>
<tr>
<td>13.</td>
<td>Are you regularly forced to use ladders for ascending and descending wind turbines because there is no other alternative means available for ascending and descending wind turbines?</td>
<td>81.25% said that they are regularly forced to use ladders for ascending and descending wind turbines because there is no other alternative means available for ascending and descending wind turbines.</td>
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<tr>
<td>14.</td>
<td>How many times per week must you climb wind turbine ladders?</td>
<td>75% must climb wind turbine ladders 5 or more times per week because there is no alternative means available for</td>
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<td>14</td>
<td>ladders because there is no alternative means available for moving about the wind turbine tower and reaching the nacelle? Note: For each time you have to ascend and descend the wind turbine without the use of an elevator or climb assist device, please count these two activities (going up and then coming back down) as 1 event.</td>
<td>moving about the wind turbine tower and reaching the nacelle. 65.63% must climb wind turbine ladders 8 or more times per week because there is no alternative means available for moving about the wind turbine tower and reaching the nacelle. 56.25% must climb wind turbine ladders 10 or more times per week because there is no alternative means available for moving about the wind turbine tower and reaching the nacelle. 37.5% must climb wind turbine ladders 14 or more times per week because there is no alternative means available for moving about the wind turbine tower and reaching the nacelle.</td>
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<tr>
<td>15</td>
<td>Is there a seasonal variation in ladder climbing activities based on the time of year? For instance, do you generally climb more ladders during the warmer months and less in the colder months?</td>
<td>87.5% of respondents indicated that Yes, there was a seasonal variation in climbing activities based on the time of year. The other 12.5% indicated that No, there were not seasonal variations in ladder climbing activities based on the time of year.</td>
</tr>
<tr>
<td>16</td>
<td>In general, what are the most active months of the year for servicing wind turbines and climbing wind turbine ladders? (select any months that apply)</td>
<td>According to the responses collected the most active months of the year for servicing wind turbines and climbing wind turbine ladders are April, May, June, July, August, September and October. If the data collected shows a general trend, it appears as though the busy season starts to ramp up in March and dramatically increases in April. It then continues to increase through June and it stays at a steady peak through July, August, and September. It then decreases slightly from September through October, but is still at a relatively high activity level. The activity level then dramatically starts to ramp down in November. This makes sense because the technicians are naturally very exposed to the elements for their occupations traveling and working outdoors.</td>
</tr>
<tr>
<td>17</td>
<td>In general, what are the least active months of the year for servicing wind turbines and climbing wind turbine ladders?</td>
<td>According to the responses collected, the least active months of the year for servicing wind turbines and climbing wind turbine ladders are December, January, and February.</td>
</tr>
<tr>
<td>18</td>
<td>In your estimation, what percentage (%) of wind</td>
<td>According to the respondents, an average of 67% of turbines are not equipped with a functioning elevator.</td>
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<tr>
<td>19.</td>
<td>In your estimation, what percentage (%) of wind turbines at the job-sites you go to are equipped with a functioning climb assist device that can be used as an alternative means of ascending and descending the ladder?</td>
<td>A wide range of responses was collected in response to this question. The respondents were given using a sliding scale between 0 and 100%. The mean response was 42.7%. 33.33% of respondents indicated that 0-25% of the wind turbine towers they encountered on the job were equipped with a functioning climb assist device. 46.67% of respondents indicated that between 30-60% of the wind turbine towers they encountered on the job were equipped with a functioning climb assist device. 20% of the respondents indicated that between 65-100% of the wind turbine towers they encountered on the job were equipped with a functioning climb assist device.</td>
</tr>
<tr>
<td>20.</td>
<td>In your estimation, what percentage (%) of wind turbines (at the job-sites you have been to) do not have any alternative means of ascending and descending besides the ladder?</td>
<td>20 out of 30 respondents said that between 40% and 85% of turbines lack any kind of alternative to the ladder, with the mean average being 48.8%.</td>
</tr>
<tr>
<td>21.</td>
<td>What is your age range?</td>
<td>The great majority (62.49%) of respondents indicated that they are between the ages 25 and 34. While 28.13% are between 35 and 49. 6.25% were in the age range of 18 to 24, and 3.13% were 50 or older.</td>
</tr>
<tr>
<td>22.</td>
<td>At what age did you begin climbing ladders in the wind turbine industry?</td>
<td>90.64% started climbing between the ages of 19 and 26. 34.38% started between the ages of 19 and 21. 40.63% started between the ages of 22 and 24.</td>
</tr>
<tr>
<td>23.</td>
<td>Approximately how many years have you been climbing wind turbine ladders in the wind industry?</td>
<td>The vast majority (87.52%) reported to have been climbing between 5 and 13 years (two were less experienced than five years and one was more experienced than 13 years).</td>
</tr>
<tr>
<td>24.</td>
<td>Approximately how much time per day do you</td>
<td>65.6% said that they spend 2 or more hours on the ladder per day. Of those who responded being on a ladder 2 or more</td>
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<td>typically spend climbing, standing on, or using wind turbine ladders?</td>
<td>hours per day, 40.6% indicated that they spend 3 or more hours on a ladder per day.</td>
</tr>
<tr>
<td>25.</td>
<td>How many hours do you generally work per day?</td>
<td>19.35% reported generally working 8 hours per day. 80.65% reported generally working &gt;8 hrs. per day. Of those who indicated working more than 8 hours per day, 61% said that they work 10 hrs. per day. Of those who reported working more than 8 hours per day, 12.91% said that they work &gt;10 hrs. per day.</td>
</tr>
<tr>
<td>26.</td>
<td>What time does your shift generally begin and end?</td>
<td>90.32% start their shift between 6 and 7 AM and 96.78% end their shift between 4 and 6 PM.</td>
</tr>
<tr>
<td>27.</td>
<td>How many hours do you regularly work per week?</td>
<td>35.49% work 40 hours per week and the remaining 64.51% work more than 40 hours per week. 45.16% of the total respondents reported working between 50 and 60 hours per week.</td>
</tr>
<tr>
<td>28.</td>
<td>How many days do you regularly work per week?</td>
<td>35% regularly work 4 days a week, 48% regularly work 5 days a week, and 16% regularly work 6 days a week.</td>
</tr>
<tr>
<td>29.</td>
<td>How many weeks do you regularly work per year performing the type of work that involves climbing wind turbine ladders? (remember that on average there are ~4.345 weeks per month)</td>
<td>The mode average (most common answer) was 48 weeks per year. 83.33% of all respondents reported working at least 44 or more weeks per year. 56.66% of all respondents indicated that they work at least 48 or more weeks per year.</td>
</tr>
<tr>
<td>30.</td>
<td>In the past, when operations have been busiest, what is the highest number of hours you might have occasionally worked in a day?</td>
<td>93.3% said that they have worked 12 or more hours when operations are busy. 26.7% reported working 14-hour days. 36.7% reported working a 16-hour day when operations were at their busiest.</td>
</tr>
<tr>
<td>31.</td>
<td>What is the highest number of hours that you have ever worked during a single day?</td>
<td>A variety of responses were received to the question “What is the highest number of hours that you have ever worked during a single day?”. The mean of responses was 17.2 hours. The single most common response for participants (mode) was 18 hours (46.67%). The second most common response was 16 hours (20.00%) and third most common response was 14 hours (13.33%).</td>
</tr>
<tr>
<td>32.</td>
<td>On a typical day, roughly how much time might you</td>
<td>The mode was 2 hours of total travel time.</td>
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<tr>
<td>33.</td>
<td>During an average work week, how many hours do you typically sleep before beginning the next work day or shift? (not including weekends or days off)</td>
<td>In answer to the question “During an average work week, how many hours do you typically sleep before beginning the next work day or shift (not including weekends or days off)?”, the mean average was 6.47 hours and the mode average was 6 hours of sleep. 10% of the respondents indicated that they sleep 5 hours per night on average between work shifts. 46.67% of respondents indicated that they sleep an average of 6 hours. 30% indicated that they sleep an average of 7 hours. 13.33% indicated that they sleep 8 hours per night on average between work shifts.</td>
</tr>
<tr>
<td>34.</td>
<td>Do you regularly work overtime hours? (i.e. more than 40 hours per week)</td>
<td>83% of respondents indicated that they regularly work overtime hours (over 40 hours per week).</td>
</tr>
<tr>
<td>35.</td>
<td>If you regularly work overtime hours, approximately how many additional hours per week do you regularly work over 40 hours per week?</td>
<td>32% reported that they regularly work 10 extra hours per week. 28% reported that they regularly work an extra 20 extra hours per week.</td>
</tr>
<tr>
<td>36.</td>
<td>Approximately how long have you been working in an occupation where you regularly climb wind turbine ladders as a part of your job?</td>
<td>The great majority of respondents to this survey were fairly experienced in the wind energy industry. 63% indicated that they have 5 to 9 years of experience climbing ladders. 30% have 10 or more years of experience</td>
</tr>
<tr>
<td>37.</td>
<td>Please estimate the total number of years you plan on working as a Wind Turbine</td>
<td>80% of respondents reported planning to work 20 or more years as a wind turbine technician. 46.67% responded that</td>
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<td>Technician (or similar occupations with similar job descriptions which include climbing wind turbine ladders as a part of the job). If you are uncertain, you can make a rough projection by considering the age you started this occupation and your current age versus the typical retirement age (generally between 60-75 years old) and then estimate how many years you would optimistically like to keep working in this same type of position.</td>
<td>they are planning on working 30 or more years as a wind turbine technician.</td>
</tr>
<tr>
<td>38.</td>
<td>In your opinion, if you were regularly provided with a functioning elevator or climb assist device that you could use at every wind turbine, would these alternatives enhance your ability to work in this occupation for as many years as you desire?</td>
<td>100% indicated YES with regard to having these workplace enhancements would enhance their ability to work in this occupation for as many years as they desire.</td>
</tr>
<tr>
<td>39.</td>
<td>Given the two options of an elevator or a climb assist device, which would provide the greatest enhancement to your planned or anticipated occupational longevity (i.e. your ability to work in this profession for as many years as you desire)?</td>
<td>100% of all respondents indicated that they would prefer a wind turbine elevator in response to this question related to career longevity and ability.</td>
</tr>
<tr>
<td>40.</td>
<td>If you were regularly provided an alternative means of ascending and descending wind turbines</td>
<td>100% of respondents said Yes it would enhance their daily productivity.</td>
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<tr>
<td>41</td>
<td>If you were regularly provided an alternative means of ascending and descending wind turbines such as an elevator or a climb assist device, which one would enhance your daily productivity the most?</td>
<td>100% of respondents indicated that a wind turbine elevator would enhance their daily productivity the most.</td>
</tr>
<tr>
<td>42</td>
<td>When using both your arms and legs to climb, generally each will be performing a certain percentage of the total work output. Approximately what percentage (%) of muscular effort is exerted by your legs in comparison to your arms when climbing up (ascending) wind turbine ladders? (NOTE: the total must add up to 100% for this question and 100% for the following question).</td>
<td>When participants of the survey were asked to estimate how they would access the percentage of muscular effort it takes from their legs versus their arms to ascend a wind turbine ladder, 100% of the responses indicated that wind turbine technicians use their legs to exert more effort than their arms when ascending wind turbine ladders. It would be natural that the legs do most of the work when climbing any type of ladder, but the mean of energy used for the legs and arms was 83.41% for the legs and 16.59% for the arms.</td>
</tr>
<tr>
<td>43</td>
<td>When using both your arms and legs to climb, generally each will be performing a certain percentage of the total work output. Approximately what percentage (%) of muscular effort is exerted by your legs in comparison to your arms when climbing down (descending) wind turbine ladders?</td>
<td>When participants of the study were asked to estimate the total amount of combined muscular effort put forth by their arms versus their legs in descending wind turbine tower ladders, the respondents indicated that their legs were performing a mean average of 87% of the work, while their arms were performing a mean average of the remaining 13% of the work.</td>
</tr>
<tr>
<td>44</td>
<td>Approximately how much do you weigh?</td>
<td>In response to a question about their body weight, 7.4% of respondents indicated that they weigh 175 lbs. or less; 37.04% indicated that they weight between 175-200 lbs.; 40.74% indicated that they weigh between 200-225 lbs.; and...</td>
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<tr>
<td>45.</td>
<td>When climbing up (ascending) wind turbine ladders, do you usually prefer to place your hands on the rungs (steps) of the ladder or upon the stiles (sides) of the ladder?</td>
<td>14.81% of respondents indicated that they weigh 225 lbs. or more. When participants were asked whether they utilize rungs or the stiles of the ladder when ascending wind turbine towers, 82.76% indicated that they prefer to use the rungs for hand placement, while the remaining 17.24% prefer to use the ladder stiles for hand placement while ascending.</td>
</tr>
<tr>
<td>46.</td>
<td>When climbing down (descending) wind turbine ladders, do you usually prefer to place your hands on the rungs (steps) of the ladder or upon the stiles (sides) of the ladder?</td>
<td>When participants were asked whether they utilize rungs or the stiles of the ladder when descending wind turbine towers, 34.48% indicated that they prefer to use the rungs for hand placement, while the remaining 65.52% prefer to use the ladder stiles for hand placement while descending.</td>
</tr>
<tr>
<td>47.</td>
<td>How much physical exertion does it take to climb wind turbine ladders? (please rate on a scale of 1 to 10 where 1 = minimal physical exertion is required (the activity has a very low energy requirement and therefore creates a very low level of physical stress) and 10 = maximum or near maximum physical exertion is required (the activity has a very high energy requirement and tends to create high levels of physical stress).</td>
<td>82.76% rated the ladder climbing activity as at least an 8 out of possible 10-point scale for physical exertion. 72.42% rated the ladder climbing activity as 9 out of 10, or a 10 out of 10 for physical exertion.</td>
</tr>
<tr>
<td>48.</td>
<td>Which is more physically stressful, climbing up or climbing back down the ladder?</td>
<td>58.62% indicated that climbing down is more stressful. 41.38% responded that climbing up was more stressful.</td>
</tr>
<tr>
<td>49.</td>
<td>Which takes more energy, climbing up or climbing back down?</td>
<td>89.66% said climbing up takes more energy. 10.34% said climbing down takes more energy.</td>
</tr>
<tr>
<td>50.</td>
<td>Approximately how much extra weight might you be supporting/carrying with you</td>
<td>62.96% of participants indicated that they might carry approximately 40-50 lbs. of extra weight on a regular or semi-regular basis while climbing up/down wind turbine ladders.</td>
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<tr>
<td>51</td>
<td>on a regular or semi-regular basis while climbing up/down wind turbine ladders? (in your rough estimate of this weight, please take into consideration any items of significance such as your helmet, harness, lanyards, and associated climbing gear - as well as any tools, equipment, replacement parts, or any other items you might occasionally have to carry with you for wind turbine service/maintenance activities).</td>
<td>14.82% indicated that they have carried approximately 55 lbs. or more, while 22.22% indicated that the extra weight they carry on a regular or semi-regular basis is approximately 35 lbs. or less. The mean average answer for this question was 43.33 lbs.</td>
</tr>
<tr>
<td>52</td>
<td>Regarding your answer to the previous question, have you ever had to support or carry more weight than this when climbing up or down a wind turbine ladder?</td>
<td>100% of the respondents answered this question in the affirmative.</td>
</tr>
<tr>
<td>53</td>
<td>Approximately what is the greatest amount of extra added weight that you have ever had to support or carry while climbing up or down a wind turbine ladder? (this could be a single instance or an event that has occurred more than once)</td>
<td>This question and a wide variety of answers. The most common answer (mode) was 75 lbs., while the mean in response to this question was 78.33 lbs.</td>
</tr>
<tr>
<td>54</td>
<td>Was supporting/carrying this extra weight a one-time event or has it occurred multiple times?</td>
<td>70.37% indicated that supporting/carrying this extra weight has occurred multiple times, while 29.63% indicated that this was a one-time event.</td>
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<td>Approximately how many meters tall are the ladders you generally climb on a regular basis? Please note that the height of the ladder should be approximately the</td>
<td>There was a variety of answers to this question. The most common answer (mode) was 95 meters. This was followed by the second most popular answer of 100 meters. 41.38% responded between 80-94 meters. 58.62% responded 95-120 meters.</td>
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<td>same as the turbine hub height (nacelle height).</td>
<td>There was a wide variety of answers to this question. The mean of the responses for this question was 104.20 meters tall (which is equal to 341.86 feet in height).</td>
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<tr>
<td>55.</td>
<td>Approximately how many meters are the tallest ladders you have ever climbed? Conversion Examples Provided to assist with your estimate: (1 meter = 3.28 feet) (100 meters = 328 feet)</td>
<td>72.41% said Yes, they do perform regular stretching exercises or they have a regular warm-up routine before climbing. 27.59% said No, they do not have a regular warm-up routine or regularly perform stretching exercises before climbing.</td>
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<td>When asked a question where they could respond by selecting any of the statements that applied to them regarding stretching routines while climbing ladders, 40% of the participants chose a response indicating that they “usually perform a warm-up routine and/or stretching exercises before climbing wind turbine ladders”. Barely more than 1/3rd (36%) of respondents indicated that they “occasionally stop and take a moment to stretch while climbing wind turbine ladders” and only 16% of respondents indicated that they “usually perform a cool-down routine and/or stretching exercises after climbing wind turbine ladders”. A small percentage (8%) indicated that they actually “prefer to not perform stretching exercises or a warm-up/cool-down routine”.</td>
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<td>56.</td>
<td>Do you regularly perform stretching exercises or do you have a regular warm-up routine before climbing wind turbine ladders?</td>
<td>89.66% said Yes, they regularly take breaks. The remaining 10.34% said No, they do not regularly take breaks.</td>
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<td>59.</td>
<td>If you do take breaks while climbing up wind turbine ladders, how many breaks do you regularly take each time you ascend (go up) the ladder?</td>
<td>When ascending the ladder, 50% of the respondents take 3 breaks, 23.08% take 4 breaks, 15.38% take 1 to 2 breaks, 11.54% take 5 or more breaks.</td>
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<tr>
<td>60.</td>
<td>If you do take breaks while climbing down wind turbine ladders, how many breaks do you regularly take each time you descend (go down) the ladder?</td>
<td>When descending the ladder, 42.31% take 2 or more breaks, 23.08% take 1 break, 34.61% of respondents take no breaks.</td>
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<tr>
<td>61.</td>
<td>On average, how many minutes long are the breaks that you take while climbing (ascending / descending) ladders?</td>
<td>23.07% take breaks that last 1 to 2 minutes, 42.31% take breaks that last 3 to 4 minutes, 34.62% take breaks that last 5 to 7 minutes.</td>
</tr>
<tr>
<td>62.</td>
<td>If you take breaks while climbing, do these breaks help you to temporarily recover?</td>
<td>7.69% said Yes, while 15.38% said No. The remaining 76.92% report that taking breaks while climbing helps them to recover somewhat but not completely.</td>
</tr>
<tr>
<td>63.</td>
<td>During the last 12 months have you experienced any work-related pain or discomfort?</td>
<td>82.76% of respondents reported having work-related pain or discomfort in the past 12 months.</td>
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<tr>
<td>64.</td>
<td>If you have experienced any work-related pain or discomfort in the past 12 months, would you attribute any of this work-related pain or discomfort to the use of wind turbine ladders?</td>
<td>86.21% said Yes. They had experienced work-related pain or discomfort in the last 12 months that they would attribute to the use of wind turbine ladders. 13.79% said No.</td>
</tr>
<tr>
<td>65.</td>
<td>Have you experienced any pain, discomfort, or a decrease in ability or range of motion during regular working hours that you could attribute to ladder climbing activities (ascending/ descending wind turbine ladders)?</td>
<td>Of the survey respondents, 85.71% reported experiencing pain, discomfort, or a decrease in ability or range of motion during regular working hours that could be attributed to ladder climbing activities (ascending/ descending wind turbine ladders).</td>
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<td>climbing activities (ascending/descending wind turbine ladders)?</td>
<td>Of the survey respondents, 85.71% reported experiencing pain, discomfort, or a decrease in ability or range of motion outside of regular working hours that could be attributed to ladder climbing activities (ascending/descending wind turbine ladders). 14.29% said No.</td>
</tr>
<tr>
<td>66.</td>
<td>Have you experienced any pain, discomfort, or a decrease in ability or range of motion outside of regular working hours that you could attribute to ladder climbing activities (ascending/descending wind turbine ladders)?</td>
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<tr>
<td>67.</td>
<td>During the last 12 months have you experienced any work-related pain, discomfort, or a decrease in ability or range of motion that lasted 3 or more days?</td>
<td>82.14% of the respondents reported having work-related pain, discomfort, or a decrease in ability or range of motion that lasted 3 or more days. 17.86% said No.</td>
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<td><em>Introductory Statement to introduce the following Questions about areas of Bodily Discomfort:</em></td>
<td>In the following section of the survey, respondents indicated areas of the body where they currently experience or have experienced discomfort in the past two years. The following are several general findings for this section of the survey.</td>
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Of the total number of responses, 20.57% indicated the spine was where they presently or in the last two years experienced discomfort directly attributable to ladder climbing activities (ascending/descending). Of that 20.57%, 9.57% reported discomfort in the lower back, 2.87% reported discomfort in the upper back, and 8.13% reported discomfort in the neck.

Of the total number of responses, 33.01% indicated an area in the upper extremities was where they presently or in the last two years experienced discomfort directly attributable to ladder climbing activities (ascending/descending). Of that group, 9.57% reported discomfort in the shoulder, 1.48% reported discomfort in the upper arm, 4.78% reported discomfort in the elbow, 5.26% reported discomfort in the forearm, 3.35% reported discomfort in the wrist, 5.26% reported discomfort in the hand, and 3.31% reported discomfort in the thumb/fingers.

Of the total number of responses, 46.42% indicated an area in the lower extremities was where they presently or in the last two years experienced discomfort directly attributable to ladder climbing activities (ascending/descending). Of this group, 7.66% reported discomfort in the hips, 2.87% reported discomfort in the thighs, 11.48% reported discomfort in the knees, 1.44% reported discomfort in the lower leg, 3.35% reported discomfort in the shin, 8.61% reported discomfort in the ankle, 6.7% reported discomfort in the arch, 2.87% reported discomfort in the heel, and 1.44% reported discomfort in the toes.

The knees were the most common single area of bodily discomfort selected. The knees were followed by the shoulders and low back. Next was the ankles, neck, hips, arch of the foot, and eventually, the hands, forearms, and elbows.

For those respondents who indicated discomfort in the Lower Back that is directly attributable to ladder climbing activities in wind turbines, a follow up question asked them to describe their symptoms. 39.58% described their lower back discomfort as Aching, 33.33% described their lower back discomfort as Stiffness, 20.83% described their lower back discomfort as Dull Pain,
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<td>4.17% described their lower back discomfort as Tension, and 2.08% described their lower back discomfort as Decreased Range of Motion.</td>
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<tr>
<td>69.</td>
<td>Neck - Please select any of the words that describe your Neck symptoms.</td>
<td>For those respondents who reported discomfort in the Neck that is directly attributable to ladder climbing activity in wind turbines, a follow up question asked them to describe their discomfort in the neck. 37.77% described their discomfort as Aching, 35.56% described their neck discomfort as Stiffness, 15.56% described their neck discomfort as Tension, 6.67% described their neck discomfort as Dull Pain, 2.22% described their discomfort as Noise, and 2.22% described their discomfort as Tingling.</td>
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<tr>
<td>70.</td>
<td>Upper Back - Please select any of the words that describe your Upper Back symptoms.</td>
<td>The respondents to the survey who indicated discomfort in the Upper Back that was directly related to climbing activities in wind turbines were asked a follow up question to define their symptoms. 35.29% described their Upper Back discomfort as Aching, 35.29% described their Upper Back symptom as Stiffness, 17.65% described their Upper Back discomfort as Tension, 11.76% described their Upper Back discomfort as Dull Pain.</td>
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<tr>
<td>71.</td>
<td>Hips - Please select any of the words that describe your Hips symptoms.</td>
<td>The respondents to the survey who indicated discomfort in their Hips as a direct result of their climbing activity on the job, were asked a follow up question to describe the symptoms they were experiencing. 26.67% described the discomfort in the Hips as Stiffness, 24.44% described their Hip(s) discomfort as Aching, 22.22% described their Hip(s) discomfort as Dull Pain, 11.11% described Decreased Range of Motion of the Hip(s), 8.89% described the Hip discomfort as Cramping, 4.44% described their Hip discomfort as Burning, 2.22% described their Hip discomfort as Tension.</td>
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<tr>
<td>72.</td>
<td>Thigh - Please select any of the words that describe your Thigh symptoms.</td>
<td>Respondents to the survey who reported discomfort in their Thigh(s) as a direct result of their climbing activities at work in wind turbines were asked a follow up question to define the symptoms. 33.33% described their Thigh discomfort as Aching, 25% described their Thigh discomfort as Burning, 16.67% described their Thigh discomfort as Tension, 16.67% described their Thigh discomfort as Cramping,</td>
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<tr>
<td>73.</td>
<td>Shoulder - Please select any of the words that describe your Shoulder symptoms.</td>
<td>There were many responses for the Shoulder(s) symptoms. For those respondents to the survey who reported discomfort in their Shoulder(s) as a direct result of work-related climbing activity in wind turbines a follow up question was asked to help define the symptoms of this discomfort. 15.52% described their Shoulder discomfort as Stiffness. 14.66% described their Shoulder discomfort as Aching. 13.79% described their Shoulder discomfort as Decreased Range of Motion. 12.93% described their Shoulder discomfort as Sharp Pain. 10.34% described their Shoulder discomfort as Weakness. 7.76% described their Shoulder discomfort as Noise. 6.03% described their Shoulder discomfort as Tingling. 6.03% described their Shoulder discomfort as Numbness. 4.31% described their Shoulder discomfort as Dull Pain. 4.31% described their Shoulder discomfort as Burning. 4.31% described their Shoulder discomfort as Tension.</td>
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<tr>
<td>74.</td>
<td>Elbow - Please select any of the words that describe your Elbow symptoms.</td>
<td>For those respondents who reported discomfort in their Elbow(s) that is directly attributable to ladder climbing activities in wind towers a follow up question asked them to describe their discomfort. 23.81% described their Elbow discomfort as Aching. 14.29% described their Elbow discomfort as Swelling. 14.29% described their Elbow discomfort as Stiffness. 11.9% described their Elbow discomfort as Burning. 9.52% described their Elbow discomfort as Dull Pain. 9.52% described their Elbow discomfort as Tension. 7.14% described their Elbow discomfort as Decreased Range of Motion. 7.14% described their Elbow discomfort as Sharp Pain. 2.38% described their Elbow discomfort as Noise.</td>
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<tr>
<td>75.</td>
<td>Upper Arm - Please select any of the words that describe your Upper Arm symptoms.</td>
<td>For respondents who indicated discomfort in their Upper Arm(s) that is directly attributable to ladder climbing activities in wind towers, a follow up question was asked to help describe their symptoms. 50% described the discomfort in their Upper Arm(s) as weakness. 50% described the discomfort in their Upper Arm(s) as stiffness.</td>
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<td>76</td>
<td>Lower Leg - Please select any of the words that describe your Lower Leg symptoms.</td>
<td>Those respondents who reported having discomfort in the Lower Leg(s) that is directly attributable to climbing activities in wind turbines were asked a follow up question to help describe their discomfort. Burning accounted for 28.55% of responses. The rest of the categories were divided evenly. Aching accounted for 14.29% of responses. Sharp Pain accounted for 14.29% of responses. Dull Pain accounted for 14.29% of responses. Weakness accounted for another 14.29% of responses. Tension accounted for the final 14.29% of responses.</td>
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<tr>
<td>77</td>
<td>Knee - Please select any of the words that describe your Knee symptoms.</td>
<td>Survey respondents who reported discomfort in their Knee(s) directly attributable to the wind turbine ladder climbing activity were asked a follow up question to describe their discomfort symptoms. The Knee(s) had the highest total amount of symptom responses collected for any part of the body. Out of the total responses collected, Aching of the Knee accounted for 16.18% of responses. Stiffness of the Knee accounted for 16.18% of total responses. Decreased range of motion in the Knee accounted for 11.76%. Swelling accounted for 11.76% of responses. Burning accounted for 11.03% of responses. Sharp Pain accounted for 10.29% of responses. Dull Pain accounted for 7.35% of responses. Weakness accounted for 6.62% of responses. Noise emitting from Knee accounted for 3.68% of responses Tingling accounted for 2.21% of responses. Tension accounted for another 2.21% of responses and finally, Numbness accounted for the final 0.74% of Knee discomfort responses.</td>
</tr>
<tr>
<td>78</td>
<td>Shin - Please select any of the words that describe your Shin symptoms.</td>
<td>Survey respondents who reported discomfort in their Shin(s) attributable to ladder climbing activities in wind turbines were asked a follow up question to define their Shin related symptoms. Burning accounted for 37.5% of responses. Sharp Pain accounted for 31.25% of responses. Aching accounted for 18.75% of responses. Stiffness accounted for 6.25% of responses. Tension accounted for another 6.25% of responses.</td>
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<td>79.</td>
<td>Ankle - Please select any of the words that describe your Ankle symptoms.</td>
<td>The respondents who reported discomfort in their Ankle(s) that is directly attributable to ladder climbing activities in wind turbines were asked a follow up question to help define their symptoms. 24.24% described their Ankle discomfort as Aching. 19.70% described their Ankle discomfort as Noise. 13.64% described their Ankle discomfort as Dull Pain. 13.64% described their Ankle discomfort as Swelling. 9.09% described their Ankle discomfort as Stiffness. 4.55% described their Ankle discomfort as Burning. 4.55% described their Ankle discomfort as Tingling. 4.55% described their Ankle discomfort as Decreased Range of Motion. 3.03% described their Ankle discomfort as Sharp Pain. 3.03% described their Ankle discomfort as Numbness.</td>
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<td>80.</td>
<td>Foot (Arch) - Please select any of the words that describe your Foot (Arch) symptoms.</td>
<td>For those respondents who reported discomfort in the Arch(es) of their Foot/Feet that is directly attributable to ladder climbing activities in wind turbines a follow up question was asked to help describe their symptoms. 33.33% described the Arch discomfort as Aching. 16.67% described the Arch discomfort as Sharp Pain. 11.11% described the Arch discomfort as Cramping. 11.11% described the Arch discomfort as Burning. 11.11% described the Arch discomfort as Tension. 5.56% described the Arch discomfort as Dull Pain. 5.56% described the Arch discomfort as Tingling. 2.78% described the Arch discomfort as Loss of Color. 2.78% described the Arch discomfort as Swelling.</td>
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<td>81.</td>
<td>Foot (Heel) - Please select any of the words that describe your Foot (Heel) symptoms.</td>
<td>For respondents reporting discomfort in the Heel(s) of the foot attributable to the ladder climbing activities in wind turbines, a follow up question was asked to help describe symptoms. 28.57% described their Heel discomfort as Tingling. 23.81% described their Heel discomfort as Sharp Pain. 23.81% described their Heel discomfort as Numbness. 14.29% described their Heel discomfort as Aching. 9.52% described their Heel discomfort as Burning.</td>
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### Survey Question

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<td>82</td>
<td>Foot (Toes) - Please select any of the words that describe your Foot (Toes) symptoms.</td>
<td>For respondents indicating discomfort in the Toes of their Foot attributable to ladder climbing activities in wind turbines, a follow up question was asked to help define their symptoms. 37.5% described their discomfort in their Toes as Tingling. 37.5% described their Toe discomfort in their as Numbness. 12.5% described their Toe discomfort as Dull Pain. 12.5% described the discomfort in their Toes as Burning.</td>
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<td>83</td>
<td>Forearm - Please select any of the words that describe your Forearm symptoms.</td>
<td>Those respondents who indicated discomfort in the Forearm(s) attributable to ladder climbing activities in wind turbines were asked a follow up question to define their symptoms. 27.78% described their Forearm discomfort as Burning. 22.22% described their Forearm discomfort as Aching. 19.44% described their Forearm discomfort as Tension. 8.33% described their Forearm discomfort as Stiffness. 5.56% described their Forearm discomfort as Dull Pain. 5.56% described their discomfort as Numbness. 2.78% described their Forearm discomfort as Cramping. 2.78% described their Forearm discomfort as Sharp Pain.</td>
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<td>84</td>
<td>Wrist - Please select any of the words that describe your Wrist symptoms.</td>
<td>Respondents who indicated discomfort to their Wrist(s) attributable to ladder climbing activities in wind turbines were asked a follow up question to help describe their symptoms. 20% described their Wrist(s) discomfort as Noise. 14.29% described their Wrist(s) discomfort as Tingling. 14.29% described their Wrist(s) discomfort as Tension. 11.43% described their Wrist(s) discomfort as Burning. 8.57% described their Wrist(s) discomfort as Weakness. 8.57% described their Wrist(s) discomfort as Numbness. 5.71% described their Wrist(s) discomfort as Dull Pain. 5.71% described their Wrist(s) discomfort as Stiffness. 5.71% described their Wrist(s) discomfort as Aching. 5.71% described their Wrist(s) discomfort as Decreased Range of Motion.</td>
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<td>85</td>
<td>Thumb/Fingers - Please select any of the words that describe your Thumb/Fingers symptoms.</td>
<td>Respondents reporting discomfort in their Thumb or Fingers attributable to ladder climbing activities in wind turbines were asked a follow up question to define their symptoms. 16.67% described their Thumb/Fingers discomfort as Stiffness. 16.67% described their Thumb/Fingers discomfort as Burning. 13.33% described the Thumb/Finger discomfort as Weakness. 13.33% described the Thumb/Fingers discomfort as Aching. 10% described the Thumb/Fingers discomfort as Dull Pain.</td>
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<td>10% described the Thumb/Fingers discomfort as Numbness. 10% described the Thumb/Fingers discomfort as Tension. 3.33% described the Thumb/Fingers as discomfort Tingling. 3.33% described the Thumb/Finger symptom as Loss of Color. 3.33% described the Thumb/Fingers symptom as Decreased Range of Motion.</td>
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<td>86</td>
<td>Hand - Please select any of the words that describe your Hand symptoms.</td>
<td>Respondents reporting discomfort in their Hand(s) attributed to the ladder climbing activity in wind turbines were asked a follow up question to describe their symptoms. 19.35% described their Hand(s) discomfort as Stiffness. 16.13% described their Hand(s) discomfort as Aching. 12.9% described their Hand(s) discomfort as Tension. 9.68% described the discomfort in their Hand(s) as Dull Pain. 9.68% described the discomfort in their Hand(s) as Numbness. 6.45% described the discomfort in the Hand(s) as Weakness. 6.45% described the discomfort in their Hand(s) as Burning. 6.45% described the discomfort in their Hand(s) as Sharp Pain. 6.45% described the discomfort in their Hand(s) as Tingling. 3.23% described their Hand(s) symptom as Decreased Range of Motion. 3.23% described the discomfort in their Hand(s) as Cramping.</td>
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<td>87</td>
<td>Approximately how long ago did you first notice any of the symptoms you reported in the previous questions?</td>
<td>88.89% of respondents to the survey who indicated discomfort directly attributable to climbing activities in wind turbines reported that they first noticed the symptoms of discomfort more than a year ago. 7.41% reported they first noticed the symptoms between the last 2-6 months and 3.71% reported the symptoms began to be noticed within the last month.</td>
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<td>88</td>
<td>During the past 12 months, approximately how often have you experienced any of the symptoms you indicated in the previous questions?</td>
<td>For those respondents who indicated they experienced symptoms of discomfort 37.04% reported in the survey that they experienced those symptoms more than once per month. 22.22% of this same group reported experiencing the symptoms more than once per week. An additional 3.7% of this same group report experiencing symptoms daily.</td>
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<td>89</td>
<td>Using a scale of 1 to 10 where 1 = Symptom severity is Negligible and 10 = the symptoms are Unbearable, how would you rate the severity of your most troublesome symptoms? (NOTE: Please use</td>
<td>Respondents to the survey who indicated discomfort directly attributable to ladder climbing activities in wind turbines rated their symptoms on a sliding scale where 1 is Negligible Discomfort to 10 being an indication of Unbearable Discomfort. The first of the two questions in this section asked about the Severity of Symptoms at the present time (“Right Now”). The second of the two questions in this section asked about the Severity of the Symptoms as experienced by the</td>
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**Survey Question** | **Response and/or Brief Analysis of Survey Responses**
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the sliders to indicate the level of your symptom severity Right Now and also indicate the severity of your symptoms when they have been at their worst.) | subject when (at any time in the past) when the symptoms “have been at their worst”. The first question (“Right Now”) generated a range of responses from 1 to 7, the mean average was 3.48. 26% of the respondents reporting on the symptoms as they were being experienced while taking the survey responded that the symptoms were above the mid-point to upper third of severity (5-7 range), while 74% of the same group reported that their symptoms were in the lower to mid-range of the scale (1-4 range). This could be attributed to the respondents being in a state of rest while taking the survey. The second question in this section which asked about a time in the past when the symptoms the subject experienced “have been at their worst” also generated a range of responses. In this case, 81.48% of the reported symptoms were in the upper most portion of the severity scale (7-10 range), while 52% of those were at the highest portion of the symptom severity scale (8-10 range).

90. What do you think caused your symptoms? Please choose from the statements below:
- Climbing and Using Wind Turbine Ladders.
- Performing another task inside the wind turbine environment.
- Performing another task outside of the wind turbine environment.
- Other (please describe) | When asked to identify or clarify what specifically they would point to as the cause of their symptoms, 92.59% of participants responded by directly attributing their symptoms to “Climbing and Using Wind Turbine Ladders”. 3.7% selected “Performing another task outside of the wind turbine environment”. An additional 3.7% selected “Other”, and identified the causes of symptoms as: being on their knees (kneeling) for long periods of time while performing work in the nacelle area AND descending from wind turbine towers using ladders after having been working on their knees for long periods of time.

91. Have you received medical treatment for these symptoms? | When asked if they had received medical treatment for their symptoms, 96.3% of respondents said that they had not received medical treatment for their symptoms. Only 3.7% of indicated that they had sought professional medical treatment.

92. Have you attempted to treat the symptoms on your own? | In response to the question whether they had attempted to treat the symptoms on their own, 51.85% of the respondents indicated that they had, while 48.15% said that they had not.
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<tr>
<td>93</td>
<td>If you have attempted to treat the symptoms on your own, what did you do?</td>
<td>A variety of responses were collected in answer to the question “if you have attempted to treat the symptoms on your own, what did you do?”. The responses included using heat and cold treatments such as heating pads or icepacks, taking over the counter pain relief medication or using topical pain relievers, resting the affected area, using muscle relaxers, stretching, taking more frequent and longer breaks, and trying not to aggravate the injured area.</td>
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<td>94</td>
<td>Could you provide an idea as to what might reduce your current symptoms?</td>
<td>A variety of responses were collected in answer to the question “Could you provide an idea as to what might reduce your current symptoms?”. The responses included having to perform less climbing, less physically stressful work, better equipped towers, more room to move around, and more frequent and consistent access to climb assist devices or wind turbine elevators. Thirteen of the responses were related to climbing ladders less frequently and having access to devices such as wind turbine elevators, climb assist devices, or any other available solutions to help the participants travel up and down the wind turbine tower more easily and efficiently.</td>
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<td>95</td>
<td>During the past 12 months have you missed one or more days of work due to pain and/or discomfort-related symptoms?</td>
<td>When asked “During the past 12 months have you missed one or more days of work due to pain and/or discomfort-related symptoms?”, 51.85% of respondents said Yes that they had, while 48.15% said No, they had not.</td>
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<tr>
<td>96</td>
<td>During the past 12 months, how many days have you missed work due to pain and/or discomfort-related symptoms?</td>
<td>Of the responses to the question “During the past 12 months, how many days have you missed work due to pain and/or discomfort-related symptoms?”, 57.15% had missed between 3 and 5 days of work, while 42.97% had missed between 6 and 12 days of work. It was not specified whether the indicated days were days-in-a-row or separate events on separate days.</td>
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<td>97</td>
<td>During the past 12 months, have you ever been on restricted duty due to pain and/or discomfort-related symptoms?</td>
<td>None of the participants reported being on restricted duty due to pain and/or discomfort related symptoms.</td>
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<td>98</td>
<td>Have your job duties been modified due to pain and/or discomfort symptoms - or have you purposely changed the way you that you</td>
<td>In response to the question regarding job duties being modified due to pain and/or discomfort symptoms - or workers purposely changing the way that usual job duties are performed due to pain and/or discomfort symptoms, 55.56% of respondents answered Yes, while 44.44% said No.</td>
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<td>perform your usual job duties due to pain and/or discomfort symptoms?</td>
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<td>99.</td>
<td>Have you changed jobs due to your pain or discomfort symptoms?</td>
<td>In answer to the question, only 7.41% indicated that they had changed jobs due to pain or discomfort symptoms while the remaining 92.59% indicated that they had not changed jobs due to their pain or discomfort symptoms.</td>
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<td>100</td>
<td>To what extent are you exposed to the ergonomic risk factor of Force?</td>
<td>Of the responses collected for Force exposure ratings on a 10-point scale, 25.93% of respondents gave the highest possible Force exposure rating of a 10 out of 10, while 29.63% rated Force exposures as an 9 out of 10. An additional 29.63% of respondents rated Force exposures as an 8 out of 10. The remaining 14.81% of respondents indicated an answer of 6 or less. The mean of responses for Force was a rating of 8.296 out of 10.</td>
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<td>*Force description – force as a risk factor includes frequently performing vigorous and intense muscular exertions in order to complete job tasks. Examples of Force could include moving the body in such a way as to require great muscular effort; or performing work in a manner that involves high levels of muscle strength and activity; or vigorous muscle activity involved with the performance of physical tasks such as lifting, pulling, climbing, or moving heavy objects in the work environment.</td>
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<tr>
<td>101</td>
<td>To what extent are you exposed to the risk factor of Posture?</td>
<td>Of the responses collected for Posture-based risk factor exposure ratings on a 10-point scale, 55.56% of respondents gave the highest possible Posture risk exposure rating of a 10 out of 10, while 25.93% rated Posture risk exposure as a 9 out of 10. The remaining 18.51% responded with an answer of 7 or less. The mean average of responses for Posture risk rating was 8.77 out of 10.</td>
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<td>(Using the slider, please rate on a scale of 1-10 where 1 = postures are relaxed and comfortable and do not produce any pain or discomfort; and 10 = postures are awkward and/or uncomfortable and frequently result in pain and/or discomfort)</td>
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<tr>
<td>102</td>
<td>To what extent are you exposed to the ergonomic risk factor of Repetition? (using the slider, please rate on a scale of 1-10 where 1 = repetitious movements are minimal and do not produce pain and/or discomfort; and 10 = repetitions are excessive and result in pain and/or discomfort) *Repetition – repetition as a risk factor involves</td>
<td>Of the responses collected for Repetition-based risk factor exposure ratings on a 10-point scale, 22.22% of respondents gave the highest possible Repetition risk exposure rating of a 10 out of 10, while 37.04% rated Repetition risk exposure as a 9 out of 10 and 25.93% gave a response rating of 8 out of 10. The remaining 14.81% responded with an answer of 7 or less. The mean average of responses for Repetition risk rating was 8.48 out of 10.</td>
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* Posture description – posture as a risk factor includes frequently assuming awkward body positions and uncomfortable ...or unnatural working positions in order to complete job tasks.  
* Repetition – repetition as a risk factor involves
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<td>frequently performing multiple cycles of quick and recurring motions in order to move from place to place or perform job tasks. Examples of repetition could include walking up and down stairs or climbing ladders as a regular part of the job. Examples would also include any work performed by using the same movement over and over again (usually several times a minute or more) in order to accomplish the task. Other reasonable examples would include assembly-line tasks typical of factory work.</td>
<td>Of the responses collected for Duration-based risk factor exposure ratings on a 10-point scale, 7.4% rated Duration risk exposure as a 9 out of 10, while 55.56% gave a response rating of 8 out of 10, and 18.52% gave a response rating of 7 out of 10. The remaining 18.52% responded with an answer of 6 or less. The mean average of responses for Duration risk rating was 7.26 out of 10.</td>
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<td>104</td>
<td>To what extent are you exposed to the ergonomic risk factor of Vibration? (using the slider, please rate on a scale of 1-10 where 1 = vibration exposure is minimal or non-existent and does not cause pain or discomfort; and 10 = vibration is often excessive and bothersome, resulting in pain and/or discomfort) *Vibration – vibration as a risk factor involves …frequently being exposed to physical sources of</td>
<td>Of the responses collected for Vibration-based risk factor exposure ratings on a 10-point scale, 11.11% of respondents gave a Vibration risk exposure rating of a 7 out of 10, while 37.04% rated Vibration risk exposure as a 6 out of 10. The remaining 51.84% responded with an answer of 5 or less. The mean average of responses for Vibration risk factor rating was 4.7 out of 10.</td>
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### Survey Question

oscillatory movement that may resonate through the whole body or through a region of the body such as the hands or feet. *Examples of being exposed to vibration would include standing on or holding onto an object that is moving in an oscillatory fashion. This could include standing on a platform or a ladder that is vibrating at a specific frequency because it is connected to heavy machinery such as a large engine or any other source of mechanical energy which is capable of inducing vibration into all connected surfaces. Some types of oscillatory movements (especially in certain lower frequencies) may be associated with feelings of fatigue, dizziness, or discomfort symptoms similar to motion sickness. Common examples of exposure to high frequency vibration might include the use of certain power tools like an oscillating power sander, an impact driver, or a chainsaw. High exposure to vibration from these types of tools hand-held power tools is commonly associated with decreased sensation in the hands as well as tingling and/or numbness.*

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<td>105</td>
<td>To what extent are you exposed to the ergonomic risk factor of Contact Stress? (using the slider, please rate on a scale of 1-10 where 1 = contact stress forces are minimal or negligible and thus do not result in pain and/or discomfort; and 10 = contact stress situations are excessive or frequent and tend to result in discomfort and/or pain) *Contact stress description – contact stress as a risk factor includes frequently using the hands or feet in the place of a tool</td>
<td>Of the responses collected for Contact Stress-based risk factor exposure ratings on a 10-point scale, 3.7% rated Contact Stress risk exposure as a 9 out of 10, while 25.93% gave a response rating of 8 out of 10, and an additional 25.93% gave a response rating of 7 out of 10. The remaining 44.43% responded with an answer of 6 or less. The mean average of risk rating responses for Contact Stress was 6.33 out of 10.</td>
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<td>such as a hammer, a chisel, or a crowbar to move, impact, or change the position of an object instead of using an actual tool that would be appropriate for the job. <em>Examples would include using a closed fist or the palm of the hand in a forceful striking motion as well as using the feet in a forceful kicking or stomping motion.</em></td>
<td>Of the responses collected for Static-Loading risk factor exposure ratings on a 10-point scale, 37.04% of respondents gave the highest possible Static-Loading risk exposure rating of a 10 out of 10, while 33.33% rated Static-Loading risk exposure as a 9 out of 10, and 11.11% gave a response rating of 8 out of 10. The remaining 18.51% responded with an answer of 6 or less. The mean average of responses for Static-Loading risk ratings was 8.37 out of 10.</td>
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<td>106</td>
<td>To what extent are you exposed to the ergonomic risk factor of Static-Loading? (Using the slider, please rate on a scale of 1-10 where 1 = static loading forces are minimal or nearly non-existent and do not cause pain or discomfort; and 10 = static-loading forces are excessively demanding and cause pain and/or discomfort). *Static-Loading description – static-loading as a risk factor involves frequently assuming</td>
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*Static-Loading description – static-loading as a risk factor involves frequently assuming*
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<td>stationary or partially stationary postures while exerting muscular force. Static efforts are typically quite fatiguing to muscles and joints. *Examples of Static loading would include performing a task while holding the arms outward and away from the body and/or above the level of the head/shoulders. These actions typically cause a rapid onset of muscular fatigue even when performed for a short period of time (several seconds to several minutes) and may commonly take place while holding a weighted object and/or a hand-tool at or above shoulder or head level. Static efforts are also associated with actions that unevenly load the muscles and joints of the body. These uneven loading scenarios could include carrying a heavy item over just one shoulder, or carrying an object under one arm for a prolonged period of time. Further examples could include common practices such as wearing a backpack on one shoulder, or holding/carrying a heavy object in only one hand - such as the handle of a heavy toolbox.</td>
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<td>107</td>
<td>To what extent are you exposed to the risk factor of Cold Temperature Extremes? (using the slider, please rate on a scale of 1-10 where 1 = cold stress situations are minimal or non-existent and therefore do not result in pain or discomfort; and 10 = cold stress situations are excessive and frequently cause whole body cooling or localized cooling of the hands and/or feet which frequently results in discomfort and/or pain) *Cold Temperature Extremes description – cold temperature</td>
<td>Of the responses collected for the risk factor of Cold Temperature Extremes on a 10-point scale, 18.52% of respondents gave the highest possible Cold Temperature Extremes risk exposure rating of a 10 out of 10. 29.63% of respondents gave Cold Temperature Extremes a risk exposure rating of 9 out of 10. An additional 29.63% gave a response rating of 8 out of 10. The remaining 22.21% responded with an answer of 7 or less. The mean average rating of responses for Cold Temperature Extremes risks was 8.074 out of 10.</td>
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<td>108</td>
<td><strong>What are the coldest environmental temperatures that you are exposed to while working during the winter season?</strong> (Using the slider, please select your temperature estimate in Degrees Fahrenheit).</td>
<td>In answer to the question “What are the coldest environmental temperatures that you are exposed to while working during the winter season?”, there was a wide range of responses. The two most common responses tied for Mode average were -10°F and -20°F. The mean average of the participants’ temperature-related responses was -14.56°F (or 14.56 degrees below zero °Fahrenheit).</td>
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<td>109</td>
<td><strong>How many weeks per year do you work while exposed to Cold Temperature Extremes?</strong> (remember there are 52 weeks/year and there are approximately 4.345 weeks per month).</td>
<td>Out of the range of responses received to the question, “How many weeks per year do you work while exposed to Cold Temperature Extremes?”, the mean average was 13 weeks.</td>
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<td>110</td>
<td><strong>To what extent are you exposed to the risk factor of Hot Temperature Extremes?</strong> (using the slider, please rate on a scale of 1-10 where 1 = heat stress situations are minimal or non-existent and therefore do not result in discomfort or other notable symptoms; and 10 = heat stress situations are severe and may be resulting in any one or more of the following symptoms from this list: excessive sweating with flushed-red skin, headache, dizziness, noticeable dehydration, lightheadedness, nausea, sickness,</td>
<td>Of the responses collected for the risk factor of Hot Temperature Extremes on a 10-point scale, 48.15% of respondents gave the highest possible Hot Temperature Extremes risk exposure rating of a 10 out of 10, while 33.33% rated Hot Temperature Extremes risk exposure as a 9 out of 10. The remaining 18.51% responded with an answer of 8 or less. The mean average rating of responses for Hot Temperature Extremes risks was 8.96 out of 10.</td>
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or generalized discomfort and/or pain) *Hot Temperature Extremes description – hot temperature extremes as a risk factor includes frequently being exposed to hot environmental temperatures in the workplace. This risk factor is also known as heat stress. Examples of heat stress situations would generally include working outdoors during the hottest and most humid portions of the summer season. Heat stress can result in the symptoms stated in the scale description above.

111 What are the hottest environmental temperatures that you are exposed to while working during the summer season?

In answer to the question “What are the hottest environmental temperatures that you are exposed to while working during the summer season?”, there was a wide range of responses. The most common (Mode) response was 120°F. The mean average of the participants’ hottest environmental temperature exposures was 117.93°F (°Fahrenheit).

112 Approximately how many weeks per year do you work while exposed to Hot Temperature Extremes? (remember there are 52 weeks/yr. and on average there are approximately 4.345 weeks per month)

Out of the range of responses received to the question, “How many weeks per year do you work while exposed to Hot Temperature Extremes?”, the mean average was 17.44 weeks.

 Figure 1. A reproduction of survey questions and an analysis of survey response data.

**Summary of Survey Data Analysis Findings**

The following is a summary of survey data analysis findings:

- Of the wind turbine maintenance technician survey respondents, 85.29% indicated that they currently climb wind turbine ladders as a regular part of their occupational duties. For the remaining 14.71% of respondents who indicated that they do not
currently climb ladders as part of their regular duties, 80% indicated they had routinely been climbing wind turbine ladders in the past two years as a regular part of their occupation, and 75% of those individuals indicated that they had been climbing wind turbine ladders on a regular basis of 3-4 times per day. The vast majority of survey respondents (85.71%) reported climbing up and down wind turbine tower ladders more than once per day. Of those, a majority (57.14%) reported climbing (ascending and descending a wind turbine tower ladder) three to five times per day. Another 10.71% indicated they ascend and descend wind turbine ladders on a very frequent basis of six to seven times per day. This establishes that the wind turbine maintenance technician survey respondents were practiced in the climbing activity and that physically climbing up and down wind turbine ladders is a daily, routine, and repetitive part of their occupational requirements.

- Regarding the ages and weights of wind turbine tower ladder technicians, the majority of respondents (62.49%) indicated that they were between twenty-five and thirty-four years of age. More than three out of four (77.78%) reported weighing between one hundred and seventy-five and two hundred and twenty-five pounds.

- Regarding work experience and time spent climbing wind turbine ladders, the great majority of respondents (90.64%) started climbing wind turbine towers between the ages of nineteen and twenty-nine years of age. The very large majority of respondents (87.52%) also indicated that they have been climbing between five and thirteen years. A majority (65.6%) also reported spending two or more hours on the ladder each day, with 40.6% of those individuals indicating that they actually spend up to three or more hours on a ladder during a typical day. This information
established that the survey respondents are highly experienced individuals in the ladder climbing activity.

- Regarding typical working hours and overtime (duration-based risk factors) for wind turbine tower technicians, a great majority of respondents (80.65%) regularly work more than eight hours per day. Of those, 61% reported working up to 10 hours per day and 12.91% reported working more than 10 hours per day. Of the respondents to the survey, 93.3% reported working twelve or more hours per day when operations were busy. A majority of 83% also indicated that they regularly tend to work more than forty hours per week. Additionally, 60% of respondents indicated regularly working 10-20 hours of overtime per week. This establishes that technicians frequently work overtime and that when operations are at their busiest, technicians may be occasionally forced/coerced/asked to work excessively long shifts.
Excessively long shifts and significant amounts of overtime work are likely to cause tiredness and exhaustion, which could then potentially lead to workplace mistakes, accidents, and occupational injuries in the short term, as well as encourage the development of musculoskeletal disorders over the long term.

- In regards to the typical time spent commuting (to and from the job) and sleep time for wind turbine tower technicians, almost half of the survey respondents (49.99%) reported spending two to three hours per day commuting to/from work. Almost half of the survey respondents (46.67%) reported sleeping for an average of six hours between work shifts. Another 10% of respondents reported only sleeping for about five hours on average between work shifts. This indicates that some wind turbine technicians may not be acquiring adequate rest between work shifts. This could lead
to fatigue and exhaustion, thereby causing job performance issues, safety issues, job satisfaction issues, and other negative consequences including not having adequate time for the body to rest and recover from work related stressors and therefore increasing the probability for the occurrence of acute musculoskeletal disorder symptoms as well as enhancing the potential for the development of prolonged and substantial musculoskeletal disorders.

- Regarding the future occupational plans of technicians, a large majority of the respondents (80%) reported that they are planning on working another twenty or more years as a wind turbine maintenance technician. Of this group, 46.67% are planning on working thirty or more years as wind turbine technicians. This is an interesting insight into the aspirations and dedication of wind turbine maintenance technicians who seemingly desire to work in this occupational field for a considerable amount of time. This data concerning the goals of wind turbine technicians to keep working for many years is especially interesting when combined with the questions regarding wind turbine elevators. One-hundred percent of the respondents said that regular access to wind turbine elevators would enable them to continue working in this occupation for many years to come, or for as long as they desire. Also, 100% of the survey respondents emphatically indicated that they would prefer wind turbine elevators over other mobility solutions, and 100% also agreed that regular and consistent access to wind turbine elevators would increase their daily productivity and efficiency.

- In regards to the muscular energy utilized in ascending/descending ladders, the respondents reported that on average, their legs exerted the vast majority (83.41%) of
the muscular effort required to climb up the ladder. The arms were reported as utilizing an average of 16.59% of the muscular effort used in climbing. When descending ladders, the respondents indicated that their legs were performing an even higher average amount of the muscular energy/effort (87%), while the arms were only utilizing an average of 13% of the overall muscular effort. It is also noteworthy that a majority (58.62%) of respondents indicated that the descent is more physically stressful than the ascent. This is an important finding because it means that although climbing up wind turbine ladders is a significantly stressful activity on the body, in actuality, for many individual wind turbine technicians, climbing back down the ladder is evidently an even more stressful activity on their bodies.

- Concerning the physical exertion required to climb (ascend and descend) wind turbine ladders, a large majority of respondents (82.76%) indicated that climbing wind turbine tower ladders would rank as at least an eight out of a possible ten for physical exertion in an activity (10 = maximum or near maximum physical exertion is required and the activity has a very high energy requirement and tends to create high levels of physical stress). Of those, 72.42% rated the ladder climbing activity as a nine or a ten out of ten in regards to the physical exertion of climbing wind turbine ladders. Also, 89.66% of the respondents indicated that the process of climbing up (ascending) generally has a higher physical energy requirement than the process of descending wind turbine tower ladders. However, when asked about which part of the ladder climbing activity is more physically stressful, climbing up or climbing back down the ladder, 58.62% said climbing down is more stressful, while 41.38% said that climbing up was more stressful. This means that the activity of ladder
climbing has an extremely high physical exertion requirement. It also means that even though 90% of respondents rated the activity of climbing up the ladder as having a higher physical energy requirement than climbing down the ladder, climbing down the ladder was rated as being more physically stressful on the body by nearly three-fifths of the survey respondents. Essentially, this means that the entire activity of climbing up and down the ladder has a high physical exertion requirement and that the ladder ascending activity is more strenuous in the way that it requires more energy, while the ladder descending activity is more strenuous in the way that it created heightened physical stress on the body.

- In regards to carrying extra weight (tools, equipment) while ascending and descending wind turbine tower ladders, the majority of respondents (62.96%) reported that they carry up to forty or fifty pounds of extra weight while climbing up and down wind turbine ladders on a regular basis. Another 14.82% of respondents indicated they carry fifty-five or more extra pounds while ascending and descending wind turbine ladders on a regular basis. 100% of the respondents indicated having to support/carry more weight than the above on occasion (more than once), with the most common amount being up to seventy-five pounds of additional extra weight. The greatest amount of extra added weight that respondents reported was an average of 78.33 pounds. This added weight, in any amount, adds to the forces and stresses placed on the body by the wind turbine ladder climbing activity, likely contributing to the occurrence of acute musculoskeletal disorder symptoms and potentially contributing to the development of work-related musculoskeletal disorders.
• When asked, generally how tall the ladders were that they were regularly climbing, 41.38% of the respondents indicated that the ladders were 80-94 meters tall, while the majority (58.62%) indicated that the ladders were 95-120 meters tall. A follow-up question asked the technicians how many meters were the tallest ladders that they had ever climbed, the mean average of the responses to this question was 104.2 meters tall, which is equivalent to 341.86 feet in height. All indications point in the direction of future wind turbines being built taller over time due to the evolution of the technology and the increasingly efficient capture of wind energy at higher elevations. This means that the turbines are becoming larger over time and thus the ladders will become longer and increasingly stressful to climb.

• In regards to training although overall training was reported by the survey respondents to be adequate (85.71%), there were 14.29% of respondents that reported their ladder climbing training to be inadequate. This is not an insignificant number. Also, there were 56.25% of respondents who reported that they were not trained in how to efficiently climb wind turbine ladders, and an additional 12.5% of respondents who did not feel that they were trained in how to safely ascend and descend wind turbine ladders. All wind turbine technicians should have the opportunity to refresh their training and to learn about new techniques or best practices for climbing the ladders regardless of whether or not the industry installs mobility devices such as wind turbine elevators or climb assist systems in all wind turbine towers. Wind turbine technicians should receive initial training as well as occasional (annual or biannual) verification of training, and re-training in order to keep them safe and maintain their ladder climbing abilities. They will always need to remain in a state of
readiness, just in case any available wind turbine mobility solutions (climb assist or elevators) were to fail, so that they could successfully manually transport themselves up or down a ladder.

- Regarding stretching, warm-up routines, and cool-down exercises, 72.41% of respondents indicated that they perform regular stretching exercises or have a warmup routine before climbing wind turbine ladders. Conversely, 27.59% responded that they do not have any regular warm-up or stretching routines before climbing. When asked follow-up questions about warm-up/cool-down and stretching, 40% of the participants indicated that they usually perform warm-up routines or stretching exercises before climbing wind turbine ladders. A little more than 1/3\textsuperscript{rd} (36%) of respondents indicated that they occasionally stretch while climbing wind turbine ladders. Only 16% of respondents indicated that they perform a cool-down routine or stretching exercises after climbing wind turbine ladders. A small percentage (8%) indicated that they prefer not to perform any stretching exercises or warm-up/cool-down routines before or after climbing wind turbine ladders. Although 72.41% of the respondents indicated that they do perform regular stretching exercises or warm-up routines before climbing, very few indicated that they perform cool downs or stretching while taking breaks. This seems odd because climbing wind turbine ladders is such a demanding and vigorous activity. It would be logical to surmise that persons performing vigorous or demanding types of activities would perform warm-up routines with stretching exercises beforehand, take breaks to stretch throughout the activity, and perform a cool-down and stretching routine after the activities to assist the muscles with stretching-out, relaxing, gaining flexibility, and
preventing injury. The regular implementation of stretching exercises and warm-up/cool-down routines have been readily accepted practices for many vigorous and demanding activities and should thus be incorporated into the wind turbine ladder climbing activity as standard everyday practice.

- In reference to regularly taking breaks while ascending and descending wind turbine ladders, 89.66% of the respondents indicated that they regularly take breaks. During the ladder ascending activity, 15.38% of the respondents reported taking one to two breaks, while 50% of the respondents take three breaks, 23.08% take four breaks, and 11.54% take five or more breaks. During the descending activity, 34.61% of respondents indicated that they take no breaks, while 23.08% take only one break, and 42.31% take two or more breaks. When they take their breaks while ascending or descending, 23.07% take one to two minute breaks, 42.31% take three to four minute breaks, and 34.62% take breaks that last five to seven minutes. When asked whether taking these breaks help the participants to temporarily recover, 7.69% responded that the breaks did help them to temporarily recover, while 15.38% said that the breaks did not help them to temporarily recover, while the remaining 76.92% reported that taking breaks while climbing helps them to recover somewhat but not completely. The fact that a great majority of the respondents indicated that taking breaks only helps them to partially recover is an enlightening piece of information. Taking breaks should help alleviate the buildup of lactic acid in the muscles, especially when combined with stretching and drinking water. The fact that 76.92% of participants reported that taking breaks only helps them to somewhat but not completely recover, makes it all the more evident that climbing up wind turbine ladders is a very rigorous
activity which requires a great deal of energy and also serves as further confirmation of the extremely strenuous nature of the wind turbine ladder climbing activity.

- In response to the question regarding experiencing any work-related pain or discomfort over the last 12 months, 82.76% of respondents reported having work-related pain or discomfort. When asked whether they would attribute this work-related pain or discomfort to the use of wind turbine ladders, 86.21% confirmed that they would attribute the use of wind turbine ladders to their work-related pain or discomfort. A third question inquired about pain, discomfort, or decrease in ability or range of motion during regular working hours that could be attributed to ascending/descending wind turbine ladders, 85.71% affirmed that they experienced pain, discomfort, or a decrease in ability or range of motion during regular working hours that they would attribute to wind turbine ladder climbing activities. A fourth question inquired about pain, discomfort, or a decrease in ability or range of motion which was experienced outside of regular working hours that could be attributed to ladder climbing activities, 85.71% that they had experienced pain, discomfort, or a decrease in ability or range of motion outside of regular working hours that could be attributed to ladder climbing activities. The next question inquired as to whether the pain, discomfort, or a decrease in ability or range of motion lasted 3 or more days, 82.41% answered in the affirmative that they had experienced pain, discomfort, or a decrease in ability or range of motion lasting 3 or more days. The high percentages of participants who indicated experiencing pain, discomfort, or a decrease in ability or range of motion that they would attribute to wind turbine ladder climbing activities is

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a further testimonial to the high potential risk of incurring musculoskeletal disorders from the wind turbine ladder climbing activity.

- The next several questions asked the participants to select any bodily areas where discomfort symptoms are present or have occurred during the past 2 years and lasted or recurred for 3 or more days. A summary of findings from the three main affected areas of the body (spine, upper extremities, and lower extremities) is directly below. This is then followed by a review of each relevant group of survey responses related to the different areas of the body for which pain or discomfort symptoms were reported.

  o Of the total number of responses, 20.57% indicated the spine was where they presently or in the last two years experienced discomfort directly attributable to ladder climbing activities (ascending/descending). Of that 20.57%, 9.57% reported discomfort in the lower back, 2.87% reported discomfort in the upper back, and 8.13% reported discomfort in the neck.

  o Also, of the total number of responses, 33.01% indicated an area in the upper extremities was where they presently or in the last two years experienced discomfort directly attributable to ladder climbing activities (ascending/descending). Of that group, 9.57% reported discomfort in the shoulder, 1.48% reported discomfort in the upper arm, 4.78% reported discomfort in the elbow, 5.26% reported discomfort in the forearm, 3.35% reported discomfort in the wrist, 5.26% reported discomfort in the hand, and 3.31% reported discomfort in the thumb/fingers.
Additionally, of the total number of responses, 46.42% indicated an area in the lower extremities was where they presently or in the last two years experienced discomfort directly attributable to ladder climbing activities (ascending/descending). Of this group, 7.66% reported discomfort in the hips, 2.87% reported discomfort in the thighs, 11.48% reported discomfort in the knees, 1.44% reported discomfort in the lower leg, 3.35% reported discomfort in the shin, 8.61% reported discomfort in the ankle, 6.7% reported discomfort in the arch, 2.87% reported discomfort in the heel, and 1.44% reported discomfort in the toes.

The knees were the most common single area of bodily discomfort selected. The knees were followed by the shoulder(s) and low back. Next were the ankle(s), neck, hip(s), and arch(es) of the foot. This was followed by the hand(s), forearm(s), and elbow(s).

• The next several questions of the survey captured from the respondents their descriptions of the symptoms they have experienced.

• Of the 9.57% of respondents who experienced lower back discomfort, 39.58% described their lower back discomfort as Aching, 33.33% described their lower back discomfort as Stiffness, 20.83% described their lower back discomfort as Dull Pain.

• Of the 8.13% of respondents who described neck discomfort directly attributable to ladder climbing activities 37.77% described their discomfort as Aching, 35.56% described their neck discomfort as Stiffness, and 15.56% described their neck discomfort as Tension.
Of the 9.57% of respondents who described shoulder discomfort directly attributable to ladder climbing activities, 15.52% described their shoulder discomfort as Stiffness, 14.66% described their shoulder discomfort as Aching, 13.79% described their shoulder discomfort as Decreased Range of Motion, 12.93% described their shoulder discomfort as Sharp Pain, and 10.34% described their shoulder discomfort as Weakness.

Of the 4.78% of respondents that experienced elbow discomfort directly attributable to wind turbine ladder climbing activities 23.81% described their elbow discomfort as Aching, 14.29% described their elbow discomfort as Swelling, 14.29% described their elbow discomfort as Stiffness, and 11.9% described their elbow discomfort as Burning.

Of the 5.26% of respondents that experienced forearm discomfort directly attributable to wind turbine ladder climbing activities 27.78% described their forearm discomfort as Burning, 22.22% described their forearm discomfort as Aching, and 19.44% described their forearm discomfort as Tension.

Of the 5.26% of respondents that experienced hand discomfort directly attributable to wind turbine ladder climbing activities 19.35% described their hand discomfort as Stiffness, 16.13% described their hand discomfort as Aching, and 12.9% described their hand discomfort as Tension.

Of the 3.35% of respondents that experienced wrist discomfort directly attributable to wind turbine ladder climbing activities 20% described their wrist discomfort as Noise, while 14.29% described their wrist discomfort as Tingling.
14.29% described their wrist discomfort as Tension, and 11.43% described their wrist discomfort as Burning.

- Of the 7.66% of respondents that experienced hip discomfort directly attributable to wind turbine ladder climbing activities 26.67% described the discomfort in the hip as Stiffness. 24.44% described their hip discomfort as Aching. 22.22% described their hip discomfort as Dull Pain, and 11.11% described Decreased Range of Motion of the hip.

- The knee(s) had the highest total amount of symptom responses collected for any part of the body. Of the 11.48% of respondents that experienced knee(s) discomfort directly attributable to wind turbine ladder climbing activities, Aching of the knee accounted for 16.18% of responses, Stiffness of the knee accounted for 16.18% of total responses. Decreased range of motion in the knee accounted for 11.76%. Swelling accounted for 11.76% of responses. Burning accounted for 11.03% of responses. Sharp Pain accounted for 10.29% of responses.

- Of the 8.61% of respondents that experienced ankle(s) discomfort directly attributable to wind turbine ladder climbing activities 24.24% described their ankle discomfort as Aching. 19.70% described their ankle discomfort as Noise. 13.64% described their discomfort as Dull Pain. 13.64% described their ankle discomfort as Swelling, and 9.09% described their ankle discomfort as Stiffness.

- Of the 6.70% of respondents that experienced foot (arches) discomfort directly attributable to wind turbine ladder climbing activities 33.33% described the arch discomfort as Aching. 16.67% described the arch discomfort as Sharp Pain. 11.11% described the arch discomfort as Cramping, and an additional 11.11%
described the arch discomfort as Burning, as well as an additional 11.11% described the arch discomfort as Tension.

- The MSD section of the survey yielded results which made it clear that the lower extremities are exposed to the most risk factors for musculoskeletal disorders in the wind turbine ladder climbing activity. This is further confirmed by the video analysis of the climbing activities which indicates that significant stress and strain is placed on the lower extremities of the subjects during the ladder climbing activity. As documented in the video analysis, the lower extremities, especially the hips, knees, and ankles, were frequently and repeatedly subject to forceful and extreme postures during the ladder climbing activity. Supplementary comments from experienced wind turbine technician study subjects confirmed that the lower extremities, especially the knees are vulnerable to the force, repetition, and other musculoskeletal disorder risk factors associated with the ladder climbing activity. Further, interviews with wind turbine technicians confirmed that they were familiar with experiencing pain and discomfort sensations in the knees and that they had experienced such during and after the recorded climbing activities.

- A second finding of the MSD section of the survey was that the upper extremities, even though they perform less muscular work during the climbing activity, are the second most common bodily areas for musculoskeletal disorder risk factors due to the wind turbine ladder climbing activity. This is also confirmed through video analysis of extreme upper extremity postures, especially regarding the shoulders which were commonly extended at high angles and subject to severe forces during the climbing activity. Forearm discomfort as seen in the survey as a risk factor was also confirmed
during the video analysis and by comments made by one of the technicians who indicated that they were experiencing significant discomfort sensations in their forearms during and after the ladder climbing activity.

- A third finding from the MSD section of the survey for general areas of bodily discomfort symptoms in the survey was that the spine was a major area of pain and discomfort symptoms. This was especially apparent regarding the lower back and neck. Again, this was confirmed in the video analysis of the climbing activities. Extreme postures of the neck and both the upper and lower spine were readily apparent. Also, lower back discomfort was confirmed by comments made by one of the technicians regarding experiencing lower back pain during and after the climbing activity.

- In regards to how long ago the participants first noticed any of the symptoms they indicated, 88.89% of respondents reported that they first noticed the symptoms of discomfort more than a year ago, while 7.41% reported they first noticed the symptoms between the last 2-6 months and 3.71% reported the symptoms were first noticed within the last month. They were also asked how often during the past 12 months they had experienced any significant symptoms. More than one-third (37.04%) of the respondents reported that they experienced symptoms more than once per month, 22.22% reported experiencing symptoms more than once per week, and 3.7% reported experiencing symptoms daily.

- Respondents were asked to rate their symptoms both “right now” and “when they have been at their worst” on a scale of 1 to 10 where 1 = Symptom severity is Negligible and 10 = the symptoms are Unbearable. The first question (“Right Now”)
generated a range of responses from 1 to 7, the mean average was 3.48 out of 10. 26% of the respondents rated the symptoms in the 5-7 range, while 74% of the same group reported that their symptoms were in the lower to mid-range of the scale (1-4 range). The lower symptom sensations could be attributed to the respondents being in a state of rest while taking the survey. The second question in this section which asked about a time in the past when the symptoms the subject experienced “have been at their worst” also generated a range of responses. In this case, 81.48% of the reported symptoms were in the upper most portion of the severity scale (7-10 range), while 52% of those were at the highest portion of the symptom severity scale (8-10 range).

- In regards to missed work days due to MSD symptoms directly related to the ladder climbing activity, 51.85% of the survey respondents that they had missed work in the past due to MSD symptoms. When those respondents who had missed work days were asked follow-up questions about how many days they had missed in the last year due to MSD symptoms, 51.15% reported missing 3-5 days of work and 42.97% had missed 6-12 days due to their symptoms. This means that MSD symptoms produced by the climbing activity are already taking a toll on the workforce and on the quantity of the work that can be completed due to absences. There is likely a production cost related to each missed day of work for each employee as well as a detriment to the company by way of potentially losing the valuable expertise of experienced employees.

- When asked to identify or clarify what specifically they would point to as the cause of their symptoms, 92.59% of participants responded by directly attributing their
symptoms to “Climbing and Using Wind Turbine Ladders”, while 3.7% selected “Other”. Those that selected their symptoms as being “Other” identified the causes of their symptoms as working on their knees (kneeling) for long periods of time while performing tasks in the nacelle area and descending from wind turbine towers using ladders after having been working on their knees for long periods of time. An additional 3.7% selected “Performing another task outside of the wind turbine environment”. When asked if they had received medical treatment for their symptoms, 96.3% of respondents indicated that they had not received medical treatment for their symptoms. Only 3.7% of indicated that they had sought professional medical treatment. This means that even though over 90% of participants directly correlate their symptoms to using wind turbine ladders, they are not seeking medical treatment for their musculoskeletal discomfort symptoms despite the fact that over 80% reported symptoms being at their worst with severity ratings in the uppermost portion of the severity scale. Also, nearly 90% of the participants who indicated discomfort symptoms revealed that they had first experienced these symptoms more than a year ago and over 60% of this group are experiencing symptoms regularly (at least once a month or more often). This is perplexing because it would be expected that a person experiencing severe symptoms at a frequent interval would seek medical treatment and advice in an effort to alleviate the symptoms. It may be that the respondents are not encouraged to address work related issues and/or seek medical treatment for any number of reasons including a lack of monetary or health insurance-based resources, a lack of time available to seek
medical treatment, job security concerns, peer group influence, pride, or portraying a self-image of toughness.

- In regards to the ergonomic risk factor of Force involved with the participants rating their job duties on a 10-point scale (where 10 = Force demands are at or above their maximum Force abilities and may at times result in pain and/or discomfort), 85.19% of the respondents rated Force as an 8, 9, or 10 out of 10. 25.93% of the respondents gave the highest possible Force exposure rating of a 10 out of 10, while 29.63% rated Force exposures as an 9 out of 10, and 29.63% rated Force exposures as an 8 out of 10. From analyzing the survey responses, it is quite obvious that Force is a significant and problematic risk factor for wind turbine technicians performing their job duties and climbing wind turbine ladders.

- In regards to the ergonomic risk factor of Posture with regard to the subjects rating their job duties on a 10-point scale (where 10 = Postures are awkward and/or uncomfortable and frequently result in pain and/or discomfort), 81.49% of the respondents rated Posture as a 9 or a 10 out of 10. Over half of the respondents (55.56%) gave the highest possible Posture risk exposure rating of a 10 out of 10, while 25.93% rated Posture risk exposure as a 9 out of 10. From analyzing the survey responses, it is quite obvious that Posture is a significant and problematic risk factor for wind turbine technicians performing their job duties and climbing wind turbine ladders.

- In regards to the ergonomic risk factor of Repetition involved with the participants rating their job duties on a 10-point scale (where 10 = Repetitions are excessive and result in pain and/or discomfort), 85.19% of the respondents rated Repetition as an 8,
9, or a 10 out of 10. Of those, 22.22% gave the highest possible Repetition risk exposure rating of a 10 out of 10, while 37.04% rated Repetition risk exposure as a 9 out of 10, and 25.93% gave a response rating of 8 out of 10. From analyzing the survey responses, it is quite obvious that Repetition is a significant and problematic risk factor for wind turbine technicians performing their job duties and climbing wind turbine ladders.

- In regards to the ergonomic risk factor of Duration involved with the participants rating their job duties on a 10-point scale (where 10 = Duration of work times are excessive and frequently result in fatigue and/or discomfort), 81.48% of the respondents rated Duration as a 7, 8, or 9 out of 10. Over half of the respondents (55.56%) rated Duration risk exposure as an 8 out of 10, while 7.4% rated it as a 9 out of 10, and 18.52% gave a response rating of 7 out of 10. From analyzing the survey responses, it is apparent that Duration is a problematic risk factor for wind turbine technicians performing their job duties and climbing wind turbine ladders.

- In regards to the ergonomic risk factor of Vibration involved with the participants rating their job duties on a 10-point scale (where 10 = Vibration is often excessive and bothersome, resulting in pain and/or discomfort), 48.15% of the respondents rated Vibration as a 6 or a 7 out of 10. Approximately one-tenth of the respondents (11.11%) gave a Vibration risk exposure rating of a 7 out of 10, while 37.04% rated Vibration risk exposure as a 6 out of 10. From analyzing the survey responses, it was not clear that Vibration is a common problematic risk factor for most wind turbine technicians performing their job duties and climbing wind turbine ladders. Vibration may be noticeable to a diverse and disparate degree of intensity depending on the
individual wind turbine environments (including such factors as specific turbine
makes, models, designs, sizes, and states of disrepair). This would explain why 11% gave a rating of 7 out of 10 which is not insignificant.

- In regards to the ergonomic risk factor of Contact Stress involved with the participants rating their job duties on a 10-point scale (where 10 = Contact Stress situations are excessive or frequent and tend to result in discomfort and/or pain), 55.56% of the respondents rated Contact Stress as a 7, 8, or 9 out of 10. 25.93% rated Contact Stress risk exposure as a 7 out of 10, while 25.93% gave a response rating of 8 out of 10, and 3.7% rated Contact Stress as a 9 out of 10. From the survey responses, it is apparent that Contact Stress is a problematic risk factor for over 50% of wind turbine technicians performing their job duties and climbing wind turbine ladders.

- In regards to the ergonomic risk factor of Static Loading involved with the participants rating their job duties on a 10-point scale (where 10 = Static-Loading forces are excessively demanding and cause pain and/or discomfort), 81.48% of the respondents rated Static Loading as an 8, 9, or 10 out of 10. Over one-third of respondents (37.04%) gave the highest possible Static-Loading risk exposure rating of a 10 out of 10, while 33.33% rated Static-Loading risk exposure as a 9 out of 10, and 11.11% gave a response rating of 8 out of 10. From analyzing the survey responses, it is quite obvious that Static Loading is a significant and problematic risk factor for wind turbine technicians performing their job duties and climbing wind turbine ladders.
In regards to the ergonomic risk factor of Cold Temperature Extremes involved with the participants rating their job duties on a 10-point scale (where 10 = Cold Stress Situations are excessive and frequently cause whole body cooling or localized cooling of the hands and/or feet which frequently results in discomfort and/or pain), 77.78% of the respondents rated Cold Temperature Extremes as an 8, 9, or 10 out of 10. Approximately 30% of respondents (29.63%) gave a response rating of 8 out of 10, and an additional 29.63% of respondents gave Cold Temperature Extremes a risk exposure rating of 9 out of 10, while 18.52% of respondents gave the highest possible Cold Temperature Extremes risk exposure rating of a 10 out of 10. The participants were also asked about what are the coldest environmental temperatures that they have been exposed to while working during the winter season. there was a wide range of responses. The two most common responses tied for mode were -10°F and -20°F. The mean of the participants temperature-related responses was -14.56°F (14.56 degrees below zero °Fahrenheit). The coldest temperature responses gathered came from 22.22% of respondents who indicated that they had experienced working environment temperatures between -24° and -41°F. When the respondents were asked a follow-up question about how many weeks per year they worked while exposed to these Cold Temperature Extremes, the mean of the collected responses was 13 weeks. From analyzing the survey responses, it is quite obvious that Cold Temperature Extremes are a significant and problematic risk factor for wind turbine technicians performing their job duties and climbing wind turbine ladders, especially in the parts of the country subject to cold temperatures and cold weather (likely the northern and central regions of the United States).
• In regards to the ergonomic risk factor of Hot Temperature Extremes involved with the participants rating their job duties on a 10-point scale (where 10 = Heat Stress Situations are severe and may be resulting in any of the following, including excessive sweating with flushed-red skin, headache, dizziness, noticeable dehydration, lightheadedness, nausea, sickness, or generalized discomfort and/or pain), 81.48% of the respondents rated Hot Temperature Extremes as a 9 or 10 out of 10. 48.15% of the respondents gave the highest possible Hot Temperature Extremes risk exposure rating of a 10 out of 10, while 33.33% rated Hot Temperature Extremes risk exposure as a 9 out of 10. When the respondents were asked a follow-up question about what are the hottest environmental temperatures they have been exposed to while working during the summer season, the most common average response was 120°F. The average of the participants’ hottest environmental temperature exposures was 117.93°F (°Fahrenheit). The participants were also asked how many weeks per year they worked while exposed to Hot Temperature Extremes and the average of responses was 17.44 weeks per year. From analyzing the survey responses, it is quite obvious that Hot Temperature Extremes are a very significant and problematic risk factor for wind turbine technicians performing their job duties and climbing wind turbine ladders, especially given the fact that nearly 50% of the respondents rated Hot Temperature Extremes as a 10 out of 10, which makes it a very prevalent and extreme risk factor.

• As previously mentioned above, the amount of physical exertion required to climb wind turbine ladders was rated by 82.76% of respondents as an 8, 9, or 10 out of 10, with 72.42% rating the ladder climbing activity as 9 or 10 out of 10 (where 10 =
maximum or near maximum physical exertion is required and the activity has a very high energy requirement and tends to create high levels of physical stress). This survey finding relates directly to several of the unfavorable ergonomic risk factor findings described above. When these adverse ergonomic risk factor conditions are combined with the sheer amount of physical exertion that is required to climb wind turbine ladders, it would be highly expected that this combination would place wind turbine technicians at great risk of incurring MSDs. The risk potential being placed upon the health and wellbeing of these employees is significant. Thus, action must be taken to alleviate this situation for employees because it cannot in good conscience be allowed to continue unabated.

- When the survey participants were asked if they could provide an idea as to what might reduce their current symptoms, the responses included having to perform less climbing, performing less physically stressful work, having better equipped towers, having more room to move around, and being provided with more frequent and consistent access to climb assist devices or wind turbine elevators. Fourteen of the responses were related to climbing ladders less frequently and having improved access to devices such as wind turbine elevators, climb assist devices, or any other available solutions to help the participants travel up and down the wind turbine tower more easily and efficiently. This relates directly to the survey question where 100% of the survey respondents indicated that having regular access to workplace mobility devices (wind turbine elevators and/or climb assist devices) would enhance their daily productivity. Additionally, 100% of the respondents also indicated that consistent access to these mobility devices (especially wind turbine elevators) would increase
their ability to work in this occupation for as many years as they desire. Furthermore, given the two options of an elevator or a climb assist device, 100% of respondents indicated that regular access to wind turbine elevators would provide the greatest enhancement to their daily productivity as well as their planned or anticipated occupational longevity.

**Goal #2.** - Perform ergonomic assessments of wind power generator tower maintenance personnel ladder climbing activities in order to quantify the extent of force, posture, repetition, duration, vibration, static-loading, and temperature-related risk factors to which employees are typically exposed.

Video recordings and still pictures of subjects performing wind turbine ladder climbing activities were taken by the researcher. Measurements and pictures of the ladder as well as significantly relevant measurements of the surrounding work environment were also documented by the researcher. The video recordings and still pictures were thoroughly assessed at a later date off-site. A manual goniometer was utilized to verify bodily postures and joint angles.

**Measurements of the Wind Turbine Environment**

Below are various measurements that were taken inside the wind turbine environment:

- Distance from the floor to the first step (rung) at the bottom of the ladder (distance from the starting position to climb up & stand on the first ladder rung) = 7” inches
- Distance between each rung (top of one step to the bottom of the next step up) = 10”
- Distance from rung to rung (top of one rung to top of next rung) = 11”
- Outer edge of rail to outer edge of rail (stile to stile) overall ladder width = 18½”
- Stile width (facing the ladder where a person might grab the ladder) = 1”
- Side to side width of each ladder rung = 16½” inches
• Width of fixed rail fall protection system mounted to center of ladder rungs = 2”
• The approximate width on left and right sides of ladder rung for foot placement = 7¼”
• Width of stiles (looking the ladder from a side profile) = 2⅜”
• Circumference dimensions of each square shaped rung = 4” (1” per each of four sides)
• Depth (protrusion) of the fixed rail fall protection safety system from center of ladder rungs = 1¼”
• Distance from the wall in back of the climber to the climbing side of the ladder at the bottom of the ladder where a person starts climbing = 32½”
• Distance from the wall in back of climber to climbing side of ladder to at the fifth deck level where the elevator stops = 32”
• Approximate dimensions of the hatch door openings on each platform that the climber must climb through to ascend and descend the ladder = 36” wide x 29.5” deep
• Distance from the edge of elevator door to the left side edge of ladder stile = 14”

Analysis of Climbing Activity from Video Recordings

Pictures (figures) of the subjects performing the wind turbine ladder climbing activities to be included in this section were carefully chosen so as to allow the anonymization of each subject by a utilizing a simple Microsoft painting tool to cover or obscure the identities of the subjects to the greatest extent possible while attempting to remain as unobtrusive as possible to the various selected activities demonstrated during the climbing cycle.
Subject A1 - Analysis of Recorded Climbing Activities

A summary of observed adverse significant risk factors including force, posture, and repetition, is provided at the end of the documented ascending and descending activity for subject A1. Subject A1 starts by inspecting his climbing gear and donning his fall protection harness outside the wind turbine environment. The technician walks up 11 steps of a metal stairway to get to the door of the wind turbine tower. He then walks through the door of the wind turbine, and over to the ladder. Facing the ladder, he begins by connecting his safety harness attachment (at the chest level D-Ring) to the fixed rail ladder safety system. He then briefly rechecks and adjusts his fall protection climbing harness as well as the ladder safety system to make sure that such equipment is ready for climbing. The technician starts with his left hand on a rung at about chest level height and his right hand on the rung that is two rungs higher (above his head level). His right shoulder and arm are extending and reaching up at a 130° angle, with his right elbow nearly straight. At the same time, he lifts his left foot up to the

Figure 2. Subject A1 starting the ascending process.
first rung of the ladder. He leans back so that there is an approximately 15° angle from his neck to his lower back (angle measured from the perspective of the vertical ladder). The right leg on the floor makes a straight line from the ankle to the neck. Simultaneously his left hip flexes to 65° and the left knee flexes to 80° while the left ankle remains in a straight and neutral position. He then pushes with the left leg and pulls with the right arm to bring his right foot up to the next step. His right hip then flexes to an 80° angle, and his right knee becomes flexed to a 90° angle. His right ankle also flexes to 15° to 20° during this motion. After the first few steps of continuing this cycle of motion, Subject A1 moves his hands so that they are gripping the stiles of the ladder instead of the rungs (see Figure 2). This means that he uses his legs to do most of the work while his hands and arms are more for balance than for pulling himself up the ladder.

Figure 3. Subject A1 continuing climbing.

As the climber gets into a regular rhythm, he is leaning back at approximately 10° to 15°, as he moves through the climbing motion his left hip is flexed at 85°, left knee flexed at 95°, left ankle flexed at 25°. At the same time is right hip is flexed at 25°, his right knee is nearly straight/locked, and his right ankle is extended by 23° to 25°. Then as he continues to climb, his
right leg pushes up and his left leg steps to the next rung. When he does this, his right hip starts to straighten out so that it is now flexed at 25° to 30°, with his right knee slightly flexed at 20°, and his right ankle extended to 15°. His left hip is flexed at 85°, with left knee flexed at 95°, left ankle flexed at 10°. He then brings his right leg up to the next rung and the cycle of climbing continues as he repeats these movements with the lower extremities (see Figure 3). During the cycle of climbing motions, the right shoulder and arm reaches up to an angle of 135°, while the right elbow becomes nearly locked and straight. The left shoulder is at approximately 90°, and left elbow is flexed at 40°. At this point in the cycle, the right hand is one rung higher than the left hand and the right hand/wrist is above the level of his climbing helmet, while left hand/wrist is approximately at the level of his chin. The upper arms are raised up and extending to the point where they tend to roll the shoulders upwards and inwards (medial rotation), nearly covering the climbers ear each time the cycle continues.

As the technician climbs up through the first hatch door, he decides to continue climbing up towards the second platform deck level before taking a break. Once he reaches the second platform deck level, he must stand to the left of the hatch door so that the door can close underneath him. As he does this, he leans over the hatch door opening with both feet positioned to the left of the hatch door and simultaneously places his right hand on a guard rail which is positioned at about waist level to the right of the ladder while his left hand grasps the left stile of the ladder. The climber then takes a three-minute rest break at the second platform deck level.

After his rest break, the subject continues to climb starting from the second platform deck level. He starts out with his hands on the rungs at eye level directly in front of him, his shoulders at 80° of extension, elbows at 25° of flexion, wrists at 10° to 15° of flexion. He then switches to hand placement gripping the side rails (stiles) of the ladder. At this point, his right shoulder is at
60° of extension, right elbow at 30° flexion, wrist approximately 5° of ulnar deviation while the right hand grips the right stile of the ladder. Simultaneously, his left shoulder is extended at 75°, with the left elbow at 35° of flexion, and the left wrist at radial deviation of 5° while gripping the left stile of the ladder. At this time, his left hand is positioned approximately four inches higher than his right hand. He then reaches up with his right hand above head level, with the right shoulder extending up to a 150° angle (reaching well above his head). As the cycle continues, his left arm and shoulder perform the same movements and the cycle repeats itself. The climber then quickly switches back to placing his hands on the rungs of the ladder and is obviously starting to use more of his upper body strength than he was previously to help pull himself up the ladder.

Each time he reaches with his hands up to the next rung, his hand is reaching above head level (see Figure 4). His shoulders regularly extend to angles of 140° to 150° each time he reaches during this part of the climbing cycle. At their lowest point, his shoulders go down to approximately 75° to 80°. In essence, this subject frequently tends to flex his shoulders between 75° and 150° during the cycle of climbing. Also, it is noted that during the cycle, once he climbs up to the point where one of his hands reaches above the level of his head, the other hand is usually near the level of his chin or collarbone, but no lower than that. At this point it is noted that the subject is leaning back at about 10°, with the right hip flexed at 35° to 40°, the right knee is flexed at approximately 15°, and right ankle is extended at 15°. At the same time, the left hip is flexed at 80-85°, left knee flexed at 90°, and the left ankle is flexed at 10°. As the subject takes another step up with the right foot to the next rung, his right hip becomes flexed at 75° to 80°, with the right knee flexed at 95°, and right ankle flexed at 5°. At the same time his left hip is then flexed at 25° to 30°, with his left knee is flexed at 30°, and left ankle is flexed at 5°. He
then takes another step and continues this same cycle of movements until he reaches the third platform deck level. He climbs up through the hatch door and steps both feet to the left again in the same manner as before to get out of the way of the door so that it can close behind/underneath him. To balance himself in this awkward position, he again reaches and laterally flexes his spine to a considerable degree so that his right hand can grasp the gate which

*Figure 4.* Subject A1 continuing climbing.
is positioned to the right of the ladder (see Figure 5). He is then standing on the third deck platform and is out of breath, so he takes another five-minute rest break.

After his rest break, the subject continues to ascend the ladder again starting from the third platform deck level (see figure 6) by positioning his right foot on the lowest rung of the ladder, left foot on the floor of the platform deck level. His right hip is flexed at 65°, his right knee is flexed at 70°, with right shin parallel with ladder. The left leg is in a normal standing posture with his foot on floor of the platform. His arms are raised with both hands grasping rungs just above his helmet level. His shoulders are at 125° of flexion and his elbows seem to be in a

*Figure 5. Subject A1 climbing up through the hatch door.*
nearly locked position or at a maximum of 5° of flexion. his right wrist is flexed at 35° and his left elbow is flexed at 15°.

*Figure 6. Subject A1 continuing to climb.*

Even though the employee’s hands are both grasping the same rung, because his body is slightly twisted with his left foot on floor and right foot on the rung above, his left shoulder is therefore lower than his right shoulder. He then pulls himself up with both arms and his right leg is pushing up from the floor of the platform. The left shoulder is flexed at 125°, and his left elbow is flexed at 35°, with the left wrist flexed at 35°. The right leg then straightens out as his left leg is pulled up to place his left foot on the next rung of the ladder. At this point, he is leaning back at 15° degrees. His left hip is flexed at 75°, his left knee is flexed at 85°, and his left ankle is flexed at 5°. Both hands placed at a rung at approximately his eye level. His shoulders are at both at 80° of extension, with elbows flexed at 30°, and wrists at 20° of flexion. Then, his left hand reaches up past his head level so that his shoulder is extended to a 140° angle. At this point, his left elbow and arm are straight, and his body is slightly twisted to the left. His
left leg then straightens out as his right hip becomes flexed to 75°, with his right knee flexed to 75°. His right hand is at a level just below his collarbone and his right shoulder is at 65° of extension, with the right elbow at 30° of flexion, with his right wrist at an approximately neutral position grasping the rung of the ladder. He is leaning back at approximately 10° to 15°. He then switches positions so that now his right hip is flexed at 15°, his right knee is straight and nearly locked, and his right ankle is extended at 15°. His left hip is flexed at 75°, with the left knee flexed at 85°, and his left ankle flexed at 10°. At the same time his right shoulder is extended to a 120° angle. His right elbow is nearly locked and straight, with his right wrist positioned several inches above head level, and his right hand is grasping a rung located approximately six inches above his head/helmet level. His left shoulder is extended to 80°, with his left elbow flexed to 30°, and left wrist flexed to 15° to 20°. As he climbs, his whole body is leaning back at 10° to 15° and sometimes up to 20°.

As the technician continues to perform the above cyclical climbing motions (see Figure 7), he eventually reaches the fourth platform deck level. Again, he climbs through the hatch door and steps to the left and leans over to the right, just as before. Once he is at the fourth platform deck level, he stops momentarily to rest. The subject then continues on climbing in the same manner as previously documented until he reaches the fifth platform deck level. Once the technician reaches the fifth platform deck level, he stops to rest for approximately three minutes. The technician starts climbing again at the fifth platform deck level which is one level below the yaw deck and from this point there are now just two shorter ladder sections that need to be climbed in order to reach the nacelle. The fifth platform deck level where the subject is standing is smaller than the other platform decks (it is approximately one-third the size of the other platform decks below. This means that there is very little room for the climber to stand to the
left of the platform hatch door as he has performed previously so that the door can close behind/underneath him. Again, the climber has to noticeably laterally flex his spine with the right hand on gate and left hand on ladder stile while his feet are placed in the back-left corner against the wall of the tower (see Figure 5 above). There is barely enough space for the subject to step to the left side to avoid getting in the way of the door closing.

Figure 7. Subject A1 continuing to climb.

The subject then climbs up eight rungs of the ladder and then stops while standing two-thirds of the way up the ladder to push up on the door above him which leads to the yaw deck. After opening the door, he climbs up the final four steps of the ladder and arrives at the yaw deck. The next ladder which leads from the yaw deck to the nacelle is about seven feet tall and is of a different construction than the other ladders that have been climbed previously. This is because it is only connected to the top of the yaw deck / the floor underneath the nacelle.
The door leading into the nacelle from the yaw deck is a different shape and size than the other doors. It is rectangular in shape and wider than it is deep, approximately 28” wide and 18” to 20” deep. This hatch door, instead of opening to the right side as the other doors do, has a hinge at the rear and there are bolts protruding from the underside of the door. This door has a tendency to close itself and the protruding bolts have a tendency to catch a climber in the back which may produce potential discomfort and/or pain as well as catching on to their fall protection harness which is a risk to climbers who might not be ready for this to occur. The climber grasps one of the upper steps of the ladder with his left hand, and with his right shoulder extended to a 170° to 175° angle (nearly straight up), he uses palm, wrist and underside of forearm to open the door pushing up with the full force of his body. During this motion, his elbow is flexed at 70°, and his forearm is twisted in a direction of pronation and his wrist is extended 15°. This motion of opening this door with his right arm ends with the shoulder and whole rest of the arm nearly straight up at a 170° to 175° angle. The climber then twists his upper torso back to the right while still holding the door in place with shoulder twisted back in back of him using forearm and hand to hold the door open as he climbs the steps leading into the nacelle. He climbs these six rungs differently and more awkwardly than the previous ladder rungs as he uses one leg at a time. The right leg, right knee, right hip to push himself up one rung at a time while the other foot follows but does not seem to help with the motion and is used as a stabilizing force because the climber has a limited amount of space and is twisting his body to hold the door open with the right arm while the left hand is gripping the ladder and as he moves up through the door, the left hand is placed on the floor surface inside the front of the door so he can lift and push his body up through the door into the nacelle.
Once the employee climbs up into the nacelle, the subject moves to an area of the nacelle where he is able to stand up straight, but in many other parts of the nacelle, there is not nearly enough space for a person of average height to stand up straight. It is also immediately obvious that when a person is working in the nacelle, there may be very little space to move around or attain a comfortable and ergonomic working position. Within the nacelle there is also an area with a small arch-shaped door called “the Igloo”. This structure is positioned directly above where the nacelle hatch door opens. This area is round shaped and is not nearly large enough for anyone taller than five feet to stand up straight. This is also an area where it would be extremely easy for a person working in the nacelle to hit his/her head. It would be important that any technicians working in the nacelle remain cautious not to trip on the awkward floor surfaces or hit his/her head on the low ceilings in certain areas. The Igloo has a doorway that leads to the rear of the turbine where a hatch door is able to be opened on the rear of the nacelle which could be opened in certain maintenance and servicing operations.

**Subject A1 - Ladder Descending Activity**

To begin the descent back down from the nacelle, the technician kneels down on the floor facing away from the door in the floor and then crawls hands and knees to reposition himself with his right leg closer to the corner of the door. He then twists and leans to the right with his torso flexing to the right side and grasps the handle of the door with his right hand. He then pulls up the door with his right hand. He then lifts up the door and crawls to the right on his hands and knees and then places his left hand on the wall for balance/support. Then while holding the door with his right hand, he moves his right leg and then left leg down through the hatch door to the most convenient rungs of the ladder below. This is obviously an awkward movement and at one point while sliding his left leg along the floor, his boot becomes briefly stuck between the edge
of the door and the floor. His spine is twisted and his left knee is flexed to a 105° angle while trying to move his left foot down to the rungs of the ladder. He then switches arms so that his right hand is now being used for balance and support while the left arm and shoulder is twisted in back of him to hold the hatch door open. As he backs down through the hatch door and climbs down the ladder, his left arm continues to hold the door open and his right arm holds onto a metal handhold which is specifically placed in this area to help climbers lift and lower themselves through this hatch door in the floor. The climber continues to use his left hand to hold the door/hatch open, but now instead of his left arm being twisted in back of him, his left shoulder and arm rotates to a position so that it faces up and forward and as he lowers himself down the ladder he holds the door with open with his left forearm. The left wrist is in an extension posture and the palm of the left hand is supinated. As he finally makes his way through the door, it closes itself and he descends down the ladder to the yaw deck. When climbing down the ladder, the subject descends slowly and carefully down the seven rungs of this ladder because it is awkward and difficult and because the climber cannot readily observe where his feet are or where the ladder rungs are located. The awkwardness of this climbing situation is compounded by the fact that there is a door pressing against the climbers back, which again can catch on the clothing or the harness of the climber during the initial descent down this ladder. The safest method to descending this ladder from the nacelle to the yaw deck is to slowly take one step at a time.

The employee’s descent continues from the yaw deck to the fifth level deck. It starts with the subject taking his pelican hook fall protection lanyard from his harness and latching it to an attachment point on the back wall above the hatch door in the floor. This action is performed so that he is always connected to a fall protection system 100% of the time when he is on the
ladder so that in the event that he was to slip and fall before reconnecting to the ladder rail safety system, his lanyard would be able to catch him mid-fall before he hit the deck below. He must have his lanyard attached to a sturdy attachment point so that he can then safely lower himself partway down the ladder and reinsert his chest level D-ring fall protection device into the rail of the ladder safety system. The idea is to be tethered to a permanently affixed object 100% of the time anytime a person is climbing up or down a wind turbine ladder. Continuing on, the subject then flexes at the waist (bends over) to grab the hatch door on the floor and lifts it open. The subject then positions himself at the left-hand side of the door/hatch opening while holding it open with his right hand. He then rotates his spine and turns around so that his back is towards the open hatch door and his front is facing in the direction of the ladder. He then crawls backwards through the hatch door and steps down onto a rung of the ladder with his right foot. At this point, he then swings his left heel back over the edge of the door opening and steps down onto the ladder while holding the hatch door open with his right hand (to keep the door open and also for balance). He needs to rotate his spine to the right to perform this motion. Then, he moves his upper body back to a more neutral position, and continuing to hold the door open with the right hand, he then uses the left hand to hold onto a metal handhold welded to the floor to assist with carefully descending the ladder. Once the subject moves approximately four steps down on the ladder, he can use his left hand to steady himself on the ladder while the right hand holds the climbing safety device attached to the front D-ring of his harness and inserts the climbing safety device back into the rail of the ladder safety system. This means that he is now momentarily attached to two separate fall protection points. Then, once the ladder safety device is firmly locked into the center rail of the ladder safety system, the climber can then safely detach his pelican hook lanyard from the attachment point above/behind his head level and clip the hook
back onto the left hip ring of his safety harness. As he performs this reaching motion, his left arm extends upwards and he twists his torso to grasp and detach the pelican hook from the connection. The subject then descends down the ladder 12 rungs to the fifth level platform deck.

Standing on the fifth level platform deck, subject A1 continues his decent by first using his right hand to pull on a metal wire device located on the right side of the ladder which helps to open the hatch door on the floor. Holding onto the left stile of the ladder with his left hand, the subject then steps onto a ladder rung just below the doorway level with his right foot, and while continuing to hold the door open with his right hand, he swings his left leg onto the appropriate ladder rung and begins his descent. As he begins to climb down the ladder, he is leaning back at an angle of approximately 25° to 30°. As he moves down towards the next steps, he keeps his right hand on the door hatch and his left hand on the ladder. At this point, his legs appear to be performing all of the body supportive muscle work, while his arms are being used primarily for balance. As he steps down through the hatch door opening, the hatch door closes above his head. As the worker descends, he leans back to a significant degree, to the point where his back seems to be scraping against the back wall of the tower. He also looks down with his head, upper back, and neck flexing at a 50° angle. He then places both hands on the left and right stiles of the ladder for balance. After taking approximately 16 steps down the ladder, with left hand on the left stile of the ladder, he lets go of ladder stile with right hand. His right hand then swings down to his side for another three steps until he performs the awkward motion of opening the door hatch in the floor of the platform deck below him, all while continuing to descend down the ladder. He does not stop or pause during these movements during the descent. As he begins the door opening motion his back becomes arched and he flexes his spine, torso, and right obliques while leaning down and to the right to a significant degree. His neck flexes significantly at
approximately 45° and his right arm reaches down to grasp a handle which is attached to a metal string device which will help open the door. At the point where he reaches the handle, his entire spine is flexed as though he could easily touch the bottom of his right foot. He does this all while continuing to descend the ladder. He is also twisting his torso to the right while his left hand is still grasping the left stile of the ladder and his left shoulder and arm are extended to a 125° angle. This is a significantly non-neutral body posture (see Figure 8).

Also, at the same time, his left knee is flexed at approximately 85° and his left hip is flexed at approximately 95°. His right foot is one rung lower than the left foot and his right arm is reaching down at a 45° angle to reach the hatch door opening device, which results in an extremely non-neutral body posture (see Figure 8). After he grasps the door opening device on the right side of the ladder, and all the while continuing to descend, he holds the door open with

*Figure 8.* Subject A1 climbing down while opening the hatch door below.
the right arm while the left arm comes off the ladder for a moment and he also looks down with his neck flexed at a 30° angle. As he continues to descend through the hatch door of the fourth level platform deck, his left hand returns back to grasp the left ladder stile, while his right hand continues to hold the hatch door open.

Once he continues down through the hatch door, he lets go of the door-opening device and then holds the door open with the side of his right shoulder. At this point during the descent he is leaning back at approximately 10°. His left hip is flexed at an 85° angle, his left knee is at an 85° angle, and his left ankle is at 15° to 20° of flexion. At the same time, his right hip is at 45° of flexion, his right knee is at 20° to 25° of flexion and his right ankle is at an approximately neutral position. He tends to steps on each rung of the ladder with the area of the boot approximating the toes/ball of the foot area. Then, his right leg moves to position so that his right hip is flexed at 90 to 95°, the right knee is flexed at 90 to 95° and right ankle is flexed at 5°. His hands are sliding down the ladder and seem to only lightly grasp onto the stiles of each side of the ladder for balance. His shoulders are generally moving between 75° to 125° of extension in front of him.

Figure 9. Subject A1 a series of 6 images taking just one step down the ladder.

At this point in the descent it is obvious that the muscles, tendons, ligaments, and joints of the legs (lower extremities) are performing all of the work and absorbing all of the employee’s
weight during each step that is taken down the ladder (see Figure 9 for a series of images showing the subject taking one step down the ladder). This is further validated by the fact that at certain points during the ladder descent activity, the subject momentarily takes both hands completely off of the ladder while continuing to climb down (see Figure 10).

Figure 10. Subject A1 taking both hands off the ladder.

The technician repeats the approach of removing both hands from the ladder on several different occasions during the ladder descent activity. This is because at certain points on the ladder there are brackets on both sides which help hold the ladder in place and somewhat interfere with his hand placement on the stiles of the ladder, so he tends to take his hands off of
the ladder momentarily as he climbs down past these obstructions. At times, both hands are removed from the ladder simultaneously, but there are other times when a quick movement will take place where each hand is briefly removed from the ladder to skip over the obstruction and then are placed back on the stile of the ladder in quick succession, which maintains three points of contact with the ladder. It is notable that the subject flexes his neck while looking downwards for most of the time that he is descending the ladder. This means that the upper back and neck are flexing forward approximately 15° or more for nearly the entire time subject climbs down the ladder (see Figure 11 for examples).

![Figure 11. Subject A1 climbing down and looking downwards.](image)

As the subject continues to climb down the ladder, he arrives at the next hatch door in the floor of the third platform deck. Again, he reaches down in the exact same unergonomic posture as described earlier and opens the hatch door below. He holds the door open in the same manner
as before and continues to descend. He barely hesitates for one second as he gets most of the way through the door. As he descends, his hips are consistently flexing at angles of 85° to 95°, and his knees are consistently flexing at 85° to 95° (see Figure 12). As before when this has occurred, this is a great deal of flexion for the hips and knees and is likely to cause future musculoskeletal disorders. His ankles are consistently moving between 15° of flexion and 30° of extension. Oftentimes the flexion of the ankle seems to be more extreme at 20° to 25°. The subject’s toes are also forced into extension (being pushed upward toward the shin) to absorb some of the impact and stress of stepping down on each rung of the ladder. As the feet land on each rung, a great deal of impact force is concentrated on a small amount of surface area on the foot roughly three to four square inches, because the stepping surface of each rung is only one inch wide. Occasionally, the subject’s ankles appear to be flexing significantly at 30° to 35°. Additionally, the entire time the subject is climbing down the ladder, the heels of his boots are turned slightly inwards towards the body at approximately 15° to 20° of abduction and his toes are pointed slightly outward and away from the body at an estimated average of 15-20° of adduction (see figures 36-38). As he continues descending down each rung of the ladder, the area of his boot near the ball of his foot and his toes continues to be the point at which he steps
Figure 12. Subject A1 climbing down the ladder.

down which means that a very small area of his foot is absorbing the weight of his body due to the rungs where he steps only being one inch wide.

It is readily observable that the subjects’ knees are acting as shock absorbers and absorbing a great deal of the impact forces associated with each step down the ladder (see figure 13). As he continues to descend, the technician eventually arrives at another platform
deck level (second deck level) and passes through the door of the second deck level in the same manner as described previously (see Figure 8 above). As he continues downward, most of the effort and stress are still concentrated on the hips and knees (see Figure 14 as well as Figure 15 below).
Figure 14. Subject A1 continuing the descent down the ladder.

Upon careful observation of the descent activity, it was observable that the subject develops an even-paced rhythmic ladder descent not too long after moving through the fifth deck level, however, this even-paced and rhythmic climbing cycle is broken up each time he passes through a hatch door in a platform deck below. At times, the subject discernably stretches backwards to a considerable degree with his abdomen pushed out in an uncomfortable looking manner, and uses his left hand to adjust the ladder safety system attachment, while his right hand holds the door open with the metal wire door-opening device. As the descent nears its end, the subject passes through another deck level (the first deck level). Again, the subject is looking down nearly the entire time he is descending the ladder, which likely causes significant amounts of upper spine and neck flexion at various angles between 15° to 45°.

As the subject approaches the last 10 steps of the ladder, he moves his hands back to grasping the rungs instead of the stiles. Once he reaches the bottom floor, he disconnects the ladder safety system from the ladder and the descending activity is completed. The subject is
visibly sweating and looks somewhat exhausted from the ladder ascent/descent activities. He reports that he feels tired/exhausted. He reports strong musculoskeletal discomfort sensations in both of his knees. He also reports soreness in the middle back and lower spine area. Before walking out of the turbine area, he again expresses that the ladder climbing activity (especially the ladder descent activity which just occurred) is exceedingly/exceptionally tough on his knees.

This is the end of subject A1 climbing activity analysis.

**Subject A1 - Summary of Observed Adverse Posture, Force, Repetition, and Other Significant Risk Factors**

Following is a summary of subject A1’s observable significant risk factors as he was ascending and descending a wind turbine tower ladder system:

- Forceful and repetitive shoulder extensions of 130° to 150° while ascending
- Repetitive but less forceful shoulder extensions of up to 125° while descending
- Forceful and repetitive knee flexion of 90° to 95° (ascending); 85° to 95° (descending)
- Forceful and repetitive ankle flexion of 25° while ascending
• Forceful and repetitive hip flexion of 85° (ascending) and up to 95° (descending)
• Significant spinal flexion during the hatch door closing activity while ascending
• Shoulder extensions of 170° to 175° while opening door to nacelle (ascending)
• Twisting (torsion) of upper torso climbing up into nacelle area
• Crawling on the hands and knees within the nacelle and yaw deck areas
• Twisting and flexing of the torso while descending from nacelle area
• Multiple awkward postures and adverse unergonomic situations noted in ascending and descending to/from the nacelle and yaw deck areas
• A technician’s clothing or fall protection harness could easily be caught on the hatch door between yaw deck and nacelle, potentially causing an unsafe situation
• Torso twisting and crawling backwards when descending through yaw deck door
• Leaning back at 25° to 30° angle while descending.
• The rungs of the ladder are only one-inch wide which focuses significant forces on a small area of the feet
• The legs perform all of the lifting and lowering related work during the descent
• Significant neck flexion at 45° to 50° angles during descent
• Significant repeated shoulder extensions of up to 125° during descent
• Forceful and repeated ankle flexion and extension during descent
• Significant and forceful repeated knee flexion of 90° to 95° during descent
• Significant and forceful repeated hip flexion of 90° to 95° during descent
• Extremely unergonomic and adverse postures while opening hatch doors during decent (spinal flexion with twisting and leaning to the right, hip flexion at 95° and
knee flexion at 85° while left shoulder is extended 125° and right arm reaches down to activate the hatch door opening device)

**Subject B2 - Analysis of Recorded Climbing Activities**

A summary of observed adverse significant risk factors including force, posture, and repetition, is provided at the end of the documented ascending and descending activity for subject B2. It takes 11 steps to get to the door of the wind turbine tower. Once the technician walks over to the ladder, he starts in a standing position directly facing the ladder and connects his safety harness attachment (at the chest level D-Ring) to the fixed rail ladder safety system. The technician then pulls back from the ladder safety system to test that it is securely attached to his harness and tightens up any loose straps on his safety harness. The technician reaches up with both hands positioned on a ladder rung which is several inches above his eye level and nearly perpendicular to the top of his climbing helmet. His wrists are pronated, and thus the

![Figure 16. Subject B2 starting the climbing activity.](image-url)
palms are facing downwards. His elbows are flexed to approximately 40° and his wrists are flexed at approximately 45° to 50°. His shoulders and upper arms are extended upwards in front of him at a 120° angle (see Figure 16). As he continues, the technician lifts his right foot up the first rung of the ladder. As he performs this action, his right hip abducts, turning out to the right side of the body so that the knee is further out to the side of the body and the heel of the foot is adducted inwards towards the centerline of the body (the outward angle of the hip and leg posture seems to be approximately 45° to 50° out of neutral). As he places his foot on the rung, his knee flexes to an approximate 80° angle and he then he flexes his left knee slightly as he begins to push up off the floor with his left foot and he pulls himself up using both his arms. He then places his left foot on the rung above where his right foot is placed. His left hip flexes to a 90° angle and his knee is flexed at a 95° to 100° angle. His left ankle is flexed at a 15° to 20° angle (toes moving up closer towards knee). His boots step on the ladder rungs at approximately

Figure 17. Subject B2 continuing the climbing activity.
the position where the ball of his foot would be located. His shoulders and upper arms extend to angles of up to 150° as he moves his hands upwards to grasp each following rung of the ladder. At their lowest point, his hands generally seem to remain up above the level of his eyes and tend to move beyond his helmet level quite often which means that his hands tend to remain outside the ergonomically ideal working zone (which is between the hips and shoulder level) and is a significant amount of shoulder extension that is taking place on a regular basis (see Figure 17). His right leg is fully extended with hip abducted outwards at approximately 40°. His hips tend to abduct outward at 30° to 40° for much of the time he is ascending the ladder. His knee is straight and seemingly locked in a straight line with his lower leg. His left ankle flexes 20° (toes moving towards the knee) as he uses his left leg to push himself up the ladder as his left foot slides inward on the rung so the arch of his boot is placed directly over the center of the rung. He then places his right foot on the same rung as his left foot.

When both of his feet are on the same rung, the hips are flexed at 30° with the rest of both legs being nearly straight. His abdomen is flexed at a 15° angle and his lower spine is flexed forward at an approximate 15° angle. His arms still above his head are at an approximate 35° to 40° angle. He holds himself in that position for a few seconds, then with his lower and upper back (spine) leaning back from the ladder at an approximate 15° angle (positioned so that his lower back and hips are closer to the ladder than his upper back and shoulders), he brings his right arm back down one rung so that it is closer to a 90° angle with his torso. At that point his right forearm is flexing and his wrist flexes at a 15° angle with his palm naturally in the supinated position holding the ladder rung. He then brings his right leg up to the next rung which flexes his right hip at 80° and his right knee at 85°. Again, his hip is abducted outwards approximately 35° while his heel is adducted inwards, and the sole of the foot is medial rotated
towards the centerline of the body. As he places his right foot on the next rung, his ankle flexes approximately 10° as he pushes up with his right leg. His left leg follows up to the next rung. As he starts to gain momentum, his spine straightens out and he continues to extend his arms reaching up to each rung above his head level (see Figure 18).

As the technician begins to develop a rhythmic climbing cycle pattern, the right arm/left leg move nearly in unison and then the left arm/right leg move nearly in unison. This is similar to a normal walking stride. When this pattern is disturbed because he becomes tired or because he goes through a platform door, he changes this pattern to a less ideal climbing pattern which creates an overextension of the obliques as well as both the arms and the legs which stretches the
body out diagonally to the right and then diagonally to the left. Measuring from the vertical stiles of the ladder it is possible to say that the subject B2 tends to lean back at approximately 15° to 20°. Then with his leg straightened, his hip flexes to about 25° to 30°. When leg is straightened and knee seems to be locked, there tends to be hip flexion at about 25°. The ankle of the leg that is straight is generally extended 25° from the neutral position. While this occurs, the opposing leg generally flexes at the hip 80° to 85° while the knee of that same leg tends to flex to 90°, and the ankle of that same leg flexes 25° to 30°. The cycle continues with each leg repeating the pattern in an opposing manner.

While climbing up to each rung, there is fairly consistent and repeated flexion of the technician’s hips at angles of 75° to 90°. The knees move between being completely straightened out (and in a seemingly locked position) to flexion angles of 80° to 95°. This is a significant degree of forceful flexion for the hips and the knees and is obviously stressful for the subject. As he continues to climb, many of these motions are repeated almost exactly. At times, the subject’s upper spine is significantly flexed and his neck flexes forward between 15° to 25°. Occasionally his neck flexes forward as much as 40° to 45°. This is especially true when the subject looks down to watch his footing. Oftentimes, as the subject climbs, he also regularly looks upwards with his neck extended backwards at an angle of 10° to 15°. Sometimes his neck extends even further to 25° or 30°. Occasionally, the subject’s hands grasp the side rails instead of the rungs, but this is an infrequent approach for this climber.

At times, when his hands are not above head level, his shoulders and elbows are abducted out from the body and his upper arm is lowered to 65° to 75° and his elbow is flexed at 40°, and his wrist is flexed at 15° to 25°. His forearms are exerting significant muscle strength and he mentioned that he feels significant musculoskeletal discomfort in his forearms as well as his
knees and his upper/lower leg muscles. He specifically states that his forearm muscles are very
tired and burning which is a sign of lactic acid build up in the muscles. At times, Subject B2’s shoulders and arms are extending (reaching up and out) at 130° to 150° while the wrist flexes between 30° to 40° when reaching and grasping the ladder rungs above his head. As he pulls himself up with his arms and pushes with his legs as well, the shoulder, arm, and wrist straighten out, and the angle at which he is grasping the rung changes. Fairly consistently, Subject B2, reaches up and out with shoulder extensions of 140° to 150° angles as his hands reach above his head/helmet level. At times if his climbing rhythm is interrupted for any reason such as passing through a door in the floor of a deck or if he stops briefly to rest, he breaks the rhythm and in the cases where this situation was noticed, his left leg and arm would both be extended while his right leg and arm would be contracted. When this occurs, it is obvious to the viewer that climbing with this motion for any length of time would excessively stretch out the oblique muscles within the climber’s torso. Also, when the climber visibly becomes fatigued, this also seems to cause a loss of favorable climbing rhythm, which potentially adds to his exhaustion.

Partway through the climb, the subject seems to be exhausted and takes a rest break. He is breathing heavily, sweating, and his face is flushed. When asked about how he was feeling, he winced and made a face indicating that he was in pain. He then motioned by pointing to his lower bicep and upper forearm area as well as the elbow area to indicate that he was experiencing musculoskeletal discomfort sensations in those areas. He also stated that his forearms hurt. Without being prompted, he also mentioned that he was feeling significant musculoskeletal discomfort sensations in other areas of the body such as his upper legs, and especially in the knees and the areas surrounding both knees.
As he resumed climbing, the hips seemed to be flexing between 75° to 85°, and the knees tended to flex at 85° to 95°. As he pulls each foot upward and places it on the next rung, the bottom of the foot or the sole of the boot turns inward, which indicates 10° to 15° of hip abduction. Both the hip and knee visibly move outward from the body (abduction). The hips and knees moving out from the centerline of the body (abducting) are likely causing this turn in the foot so that it does not appear to be moving or landing flatly from one rung to the next with a flat foot. The outward movement (abduction) of the hips and knees away from the centerline of the body causes the sole of each foot to make a sort of rolling motion as it first contacts the rung, and as the stepping motion continues and the weight of the body is distributed to each foot, the sole of the foot flattens out on the rung. This can be readily observed during slow motion video playback. The subject momentarily stops and holds himself in place forcefully with his arms while he uses his feet to kick out a temporary rest platform on the ladder. He then stands and rests on the temporary platform for 20 seconds (see Figure 19). These small rest platforms which can be kicked out from the ladder occur between deck platforms at an interval of every nine meters. He then resumes climbing in order to reach an actual platform deck where he can

*Figure 19.* Subject B2 kicking out the rest platform on the ladder.
take a longer and more comfortable rest break. Once climbs up through the platform hatch door (see Figure 20), he arrives at the platform deck and the door shuts behind/underneath him.

![Figure 20. Subject B2 climbing through a platform hatch door.](image)

The climber is obviously winded from the very hard work of climbing up the vertical wind turbine ladder, and thus takes a five-minute break at the platform. Once it is safe to do so, he detaches his ladder safety harness connector from the safety rail system on the ladder and he then begins to pace back and forth on the deck while breathing heavily. He also leans up against the ladder to rest his arms and legs.

When asked if he felt any symptoms of discomfort or pain, he again pointed at his forearms but this time he specifically pointed at the underside of his forearms as well as the tendons that run down the underside of the forearms between his wrists and elbows. This is indicative of overuse of the musculature and tendons that run down the middle of the forearm from the elbow to the wrist. It was obvious from his gestures and words that his entire arm from the elbow to the wrist was experiencing discomfort and pain. The subject then reattaches his fall protection harness to the ladder safety rail system and continues to climb up to the next platform deck in the same manner as was previously described. After taking another 5-minute break, the subject demonstrates the descending process and climbs down the ladder.
Figure 21. Subject B2 images of the ladder descending activity.

Figure 22. Subject B2 continuing the ladder descending activity.
Subject B2 - Ladder Descending Activity

As he descends, Subject B2’s hips consistently flex 85° to 95°, and his knees consistently flex to 85° to 95° (see Figures 21 and 22). This significant amount of forceful hip and knee flexion would be expected to cause potential future musculoskeletal disorders if it was repeated over an extended period of time. The subject also frequently incurs 15° to 25° of ankle flexion and 25° to 35° of ankle extension. His shoulders move between 80° to 155° of extension during the descent. When he leaves one of his arms well above his helmet level, at times his shoulders reach up to 155° of extension. Wrist movement varies between 30° of extension and 45° of flexion. The subject’s neck varies between 10° and 45° of flexion while climbing down the ladder and looking down to observe his foot placement during the descent activity. When the subject reached the bottom of the ladder, he was breathing heavily and was sweating profusely. Without being prompted, he commented that he was feeling musculoskeletal disorder type symptoms in his forearms, wrists, knees, hips, and upper legs. He also frankly suggested that anyone who doesn’t think the wind turbine ladder climbing activity is extremely exhausting, stressful, and potentially harmful to the human body over a period of time should try it and find out for themselves.

Subject B2 - Summary of Observed Adverse Posture, Force, Repetition, and Other Significant Risk Factors

Following is a summary of subject B2’s observable significant risk factors as he was ascending and descending a wind turbine tower ladder system:

- Repeated forceful shoulder extensions of 120° to 150° while ascending
- Hands regularly raised above ideal position above head/helmet level (ascending)
- Significant and frequent hip abduction of 30° to 40° while ascending
- Forceful wrist flexion 15° to 50° while ascending
- Forceful ankle flexion of 15° to 30° while ascending
- Forceful and repetitive knee flexion of 90° to 100° while ascending
- Forceful and repetitive ankle flexion of 25° while ascending
- Forceful and repetitive hip flexion of up to 90° while ascending
- Leaning back at 15° to 20° while ascending
- Neck flexion frequently at 15° to 25° and occasionally up to 45° while ascending
- Forceful and repetitive hip flexion of 85° to 95° during descent
- Forceful and repetitive knee flexion of 85° to 95° during descent
- Forceful and repeated ankle flexion of 15° to 25° during descent
- Forceful and repeated ankle extensions of 25° to 35° during descent
- Forceful and repeated shoulder extensions of up to 155° during descent
- Forceful and repeated wrist extension 30° during descent
- Forceful and repeated wrist flexion of up to 45° during descent
- Significant and repeated neck flexion of up to 45° angles during descent

**Subject C3 - Analysis of Recorded Climbing Activities**

A summary of observed adverse significant risk factors including force, posture, and repetition, is provided at the end of the documented ascending and descending activity for subject C3. Before climbing, the subject ascends 11 steps up the exterior staircase to the wind turbine tower door. Then he walks through the door, over to the ladder, and connects his ladder safety system attachment to the rail that runs up and down the middle of the ladder. When asked about what other preparation activities he might perform or other things that he might consider before starting his ascent, the technician commented that normally he would have some water
with him, as well as any tools, or equipment that he might need. This would then add extra weight during the climbing (ascending/descending) activity. The subject begins with both of his hands placed on a ladder rung near his eye level. His shoulders and upper arms are extended at an 85° angle, both elbows are flexed at approximately 55°, and the wrists flexed at approximately 40°. The subject starts with his left foot on first ladder rung. His left arm moves first to next ladder rung significantly above his head to the point where his wrist level is slightly above the top of his climbing helmet (wrist flexed at 40° to 45°), with his left shoulder extended up to a 140° angle and the corresponding elbow is flexed at 20° to 25°. He is looking upwards with his neck extended at a 30° angle. The subject then lifts right leg and sets his right foot down on the next rung of ladder. His right hip flexes 85° to 90°.
While ascending the ladder, the subject is leaning back at a 7° to 10° angle. His right knee is flexed at 85° with his right shin situated approximately 3° away from being parallel with the ladder. Then, as he climbs his right knee straightens out and his right hip reduces to a 40° angle of flexion, his left hip flexes to an approximate 90° and his left knee flexes 90° to 95° while the left shin then becomes nearly parallel with ladder. As he continues to climb, his left leg straightens out with the knee flexing to approximately 20° to 25° and the left hip is moving to a 50° angle of flexion. Then, at this moment instead of his left shin being parallel with ladder as
it was previously, the shin moves back at a 15° angle, while the subject’s upper torso leans back a little more to an approximate 10° to 15° angle (as measured from the perspective of the vertical ladder). Following this motion, his right leg moves up towards the next rung of the ladder, with the right hip flexing 85° to 90°. At the same time, as his right hip flexes, his right knee swings out with hip abduction of approximately 15° to 20° and when his right foot meets the ladder rung, his right knee reaches an approximate 95° angle of flexion. The right shin then becomes nearly parallel with the ladder. These forceful exertions and fairly extreme angles of hip and knee flexion could lead to musculoskeletal disorder symptoms of the lower extremities, especially the areas in which the force is focused, within the hips and knees (see Figure 23). It is observable that when the technician steps up to each rung of the ladder, his boot tends to land on the rung in the area of the foot between the arch and the ball of the foot. Since the rungs are only one inch wide, this means that the weight of his body is resting on an approximate three to four square inch surface of the foot, which concentrates the forces involved on this area of the foot. During the climbing activity, the ankles tend to move from the neutral position to flexion, then back to neutral, then to extension and back to the neutral position. During the flexion part of the cycle, the ankles tend to move anywhere between 15° and 25° of flexion. Then the ankles pass back through the neutral position and move towards 20° to 30° of extension on a regular basis. The ankles tend to flex and extend at least of 15° to 20° during each climbing movement cycle.

Continuing on, the climber’s shoulders are consistently reaching 130° angles of extension while he reaches well above his head/helmet level. This extent of shoulder extension is above the ideal working shoulder position. When each of his shoulders cycle back and forth reaching this high degree of extension, at the highest point of shoulder extension, the elbow of that arm tends to be placed in various degrees of flexion between 10° and 25°. During the part of the
climbing cycle where the climber pulls himself up the ladder, one of the subject’s arms and shoulders will tend to be in a nearly full extension, while the hand of the opposing arm will tend to be holding onto a rung which becomes closer to parallel with the face and chin area as he moves upward. During this point where the hand becomes more parallel to the face/chin area, the subject’s elbows become flexed at angles generally between 80° and 100°. There is obviously forceful flexion taking place as the climber pulls himself up the ladder and also pulls himself towards the ladder and balances himself with his arms so as not to fall backwards while climbing. Both his right and left wrists reach at or above the helmet level very consistently as he climbs. At the lowest point his wrists are at a level comparable to his jaw line and at the highest point, such reach above the level of the top of his climbing helmet. The wrists tend to move between 15° to 45° of flexion. His neck very regularly extends by 20° to 30° to look up in the direction that he is climbing. This level of neck extension would likely be greater if he was not regularly leaning back and away from the ladder at a 7° to 10° angle. At times the subject looks far up above in the distance so that he is looking up at an approximate 160° angle, which means that he is holding his upper spine and neck in extreme angles of extension. Although this extreme neck posture is temporary while the climber occasionally looks far up in the distance for three to five seconds at a time, such extreme neck extensions combined with the frequently observed 20° to 30° neck extensions (which are also held for much longer periods of time during the ladder ascending activity) could certainly lead to musculoskeletal disorder symptoms of the upper spine area.

During the ladder ascending activity, the subject is breathing heavily and stops to rest in the middle of the ladder for approximately 30 seconds. Afterwards, he starts climbing again and
continues climbing the ladder as described previously. Hips regularly flexing 85° to 90°, knees regularly flexing 90° to 95°, and shoulders regularly extending to 130° (see Figure 24).

![Subject C3 climbing the ladder](image)

*Figure 24. Subject C3 continuing the climbing activity.*

After taking another 24 steps up the ladder in this same manner, the worker arrives at a platform deck and stops to rest for approximately 4 minutes. When this rest break ends, Subject C3 begins to climb again. When he raises his right leg towards the next step, his right hip moves into a 95° angle of flexion while abducting outwards approximately 30°. At the same time, the right knee flexes to approximately 97° and moves out away from the body due to the 30° hip flexion. Also, at this point, the right ankle is in an approximate neutral position, but the sole of the foot is visibly turned inwards due to 30° of hip abduction. His left leg follows in this same cycle of motion. At certain points during this continuous cycle of motions, the subject reaches up above his head with his hands to grasp each of the next rungs. During this time of reaching upwards, his shoulders regularly extend up to 130° angles. Occasionally it is observable that the subject extends his shoulders all the way up to 150° angles while reaching far above the level of his head/helmet. This is a very significant degree of regular and occasional shoulder extension.
which also appears to be performed in a forceful manner. During the climbing cycle, the subject’s the knees are regularly flexing at angles of 90° to 95° and his hips are regularly flexing at angles of up to 95°. This motion is repeated in a fairly consistent cycle as the technician climbs up the ladder (see Figure 25). It was observed that although the technician uses both his legs and arms to propel himself up the ladder, the legs perform the majority of the work.

![Figure 25. Subject C3 climbing up towards a platform deck.](image)

**Subject C3 - Ladder Descending Activity**

When Subject C3 is climbing down, his legs appear to be performing most of the body supportive-related work. As he climbs down, his general overall posture is different. His arms and legs are performing a similar function but the postures are different because instead of pushing with his legs and pulling with his arms to climb up the ladder, he is instead having to
lower himself in a controlled fashion, and thus resist the forces of gravity by carefully
descending the ladder in a controlled manner (see Figure 26).

Figure 26. Subject C3 images of the descending activity.

The subject mentions that climbing down the ladder is actually harder than climbing up,
especially on the joints of the lower extremities. During the descent, several noteworthy postures
were observed. For instance, during the descent, he leans back further and relies on the ladder
safety system attached to his harness. His torso tends to be further away from the ladder than it
was when climbing up (it is at least one foot away from the ladder, while his waist may be up to
18” away from the ladder during the descent (see Figure 27).
Additionally, while descending, his back tends to be arched (forward spinal flexion of 30° or more) (see Figures 27 and 28). During the descent, it is noted that his shoulder extends to a 125°
angle and his arm forms a nearly straight line from his shoulder to his wrist and his wrist is flexed at 25°. At the same time, his left shoulder is extended at a 70° angle, the elbow is flexed at 40° and the wrist flexed at 20°. The right hip exhibits a 75° of flexion. If his torso was straight up and down (and parallel with the vertical ladder) instead of leaning back in the way that he tends to do, then the hips would actually be flexing at a 90° angle on a regular basis, but because his back is arched and he is leaning back away from the ladder, the hips are regularly flexing 105° to 110° angles during the descent activity. In this position of extreme hip flexion, the knees regularly tend to flex up to a 110° angle. In certain instances, it was noted that one hip might be was flexing up to 105° or more (left hip) and at that same time his other hip (right hip in this instance) was flexing at a 135° angle. This is a significant amount of hip flexion for both hips. It was also noted that during the descent, the shoulders were often extended at 130° or more, but unlike the ascending activity, it is generally only one of the arms that is performing this extension well above the head level, instead of both at arms remaining above head level (see Figure 29). During the descent, his arms were oftentimes lower than during the ascending activity, but hardly ever below 85° or 90° of shoulder extension. It is observable that when a hand is above his head, it is holding onto a rung and bearing some of his weight as he lowers himself down to the next step (generally with the foot on the opposing side of the extended shoulder/arm). When his wrist is at or above the level of his helmet, his shoulder quite often rolls upward (medial rotation) to the point where the shoulder covers his ear. At times he establishes a smooth rhythm as he descends, but any time he starts to reach a platform deck below (when he has to reach down with the right arm to open the door), he loses this natural rhythm and momentum. As the cycle of downward climbing movements is repeated, subject C3 eventually reaches the bottom of the ladder.
Subject C3 Summary of Observed Adverse Posture, Force, Repetition, and Other Significant Risk Factors

Following is a summary of subject C3’s observable significant risk factors as he was ascending and descending a wind turbine tower ladder system:

- Repeated forceful shoulder extensions of up to 150° while ascending
- Hands are regularly raised above the ideal position (above head/helmet level) while ascending
- Significant and frequent hip abduction of 30° while ascending
- Significant and repeated forceful elbow flexion of up to 100° while ascending
- Forceful and repeated wrist flexion up to 45° while ascending
- Forceful and repeated ankle flexion of 15° to 25° while ascending
- Forceful and repeated ankle extension of 20° to 30° while ascending
- Forceful and repetitive knee flexion of up to 97° while ascending
- Forceful and repetitive hip flexion of up to 95° while ascending

Figure 29. Subject C3 climbing down to the second platform near the end of the descent.
• Leaning back at 10° to 15° while ascending
• Repeated neck extension of up to 30° while ascending
• Occasional extreme extension of spine and neck to look upwards at a 160° angle while ascending
• Forceful and repetitive hip flexion of 105° to 110° during descent
• Forceful occasional extreme hip flexion of up to 135° during descent
• Forceful and repetitive extreme knee flexion of up to 110° during descent
• Forceful and repeated shoulder extensions of up to 130° during descent
• Forceful and repeated wrist flexion of up to 20° to 25° during descent
• Significant forward spinal and neck flexion of approximately 30° to 40° (descent)

Additional Observations and Commentary from the Climbing Activity

There were additional observations and commentary collected from the video recordings of wind turbine technicians who performed the ladder climbing activity. There were also informal discussions which occurred with several technicians which provided supplemental informative commentary and provided additional enlightening information regarding occupationally-based musculoskeletal disorder risk factors and other general concerns related to the profession of wind turbine maintenance technicians. The maintenance technicians had a number of insightful remarks that they shared which relate to several potential musculoskeletal disorder risk factors including force, posture, repetition, duration, vibration, static loading, and temperature extremes.

**Force.** Obvious force-related concerns arose from examining the forces involved in the wind turbine ladder climbing activity. The observed wind turbine technicians were routinely exposed to significant amounts of forceful movements during the wind turbine ladder climbing
activity. Additionally, the technicians reported that they regularly carry over 20 pounds of tools up and down the ladder each time they climb to perform regular servicing and maintenance work. It should be noted that this weight estimate does not include any specialized tools or spare parts that they may need in order to perform certain types of wind turbine servicing and maintenance activities. The technicians also reported that their personal climbing harnesses were specifically rated to carry an extra 40 pounds of material and equipment as an external load attached by a rope or a lanyard to the back of their climbing harnesses. Given that they reported regularly carrying an extra added weight of over 20 pounds of tools, it would not take much more weight to exceed the safe weight limit of their harnesses, which is not only a personal protective equipment related issue, but is also an ergonomic force-related concern, as well as being a potential concern for additional musculoskeletal disorder risk factors such as posture, static loading, and repetition. The technicians also reported that if the weight of the external carried load is not centered or positioned correctly or if the load shifts while climbing, then the climber will likely notice discomfort in the hips, knees, and the side of the body that is carrying the majority of the weight of the load which is a definite static loading-based risk factor. Another one of the technicians also mentioned that his hands sometimes become extremely tired and sore after climbing up or down the ladder because of the length of time and the forces which are involved with grasping and holding onto the ladder rungs during the ascending and descending process. Several of the technicians who were interviewed noted that although climbing up the ladder is a significantly stressful event, climbing back down (descending) the ladder can be even more strenuous on the legs. Most specifically, the forces involved during the descending activity on the joints of the knees seemed to be of the greatest concern to the technicians interviewed. Another comment received from the technicians was that during wind
turbine work activities, they are frequently experiencing situations which place significant stress and non-natural postural loading upon the joints of the body for significant amounts of time throughout the working day. This means that they must periodically self-assess to determine whether they need to take a break from certain working activities which cannot easily be stopped and because of the expectations for them to continue working at a certain pace in order to complete expected job tasks. This means that they often work through the pain of certain activities rather than take necessary breaks in order to complete their daily work tasks in a low-risk manner. This is exemplified in the wind turbine ladder climbing (ascending/descending) activity because it is also not very comfortable or convenient to stop and take a break in the middle of climbing a wind turbine ladder. It is even more obvious from these various force-related comments provided by the technicians themselves that force is certainly a definite musculoskeletal disorder risk factor concern involved in the wind turbine ladder climbing activity.

**Posture.** While informally conversing with the technicians, it was clear from their statements that they fully recognize the frequent non-natural bodily positions and physically stressful working conditions and that they are subjected to on a daily basis when climbing wind turbine ladders as well as performing many other various tasks included in their jobs. The technicians are aware that their working conditions are unergonomic and they do their best to deal with the situation by taking breaks when they can, but they cannot always take breaks when necessary. One of the technicians reported that there just isn’t a better option to choose/change a bodily position or to reposition themselves while working in order to complete a task from a more ergonomically ideal body position. This is true for a great number of working activities and situations that they encounter. One of the technicians also stated that oftentimes he might
find himself working in an unergonomic position for an hour or more. There are also job tasks that are stressful on a technician's shoulders because there is a lot of overhead work where an individual has to raise their hands and arms above the head level for periods of time which is well above the ideal postural working positions (this occurs while both ascending and descending ladders as well as other maintenance related activities performed inside the turbine towers). The technicians also stated that after performing a variety of activities during the course of their work shift, they commonly experience whole-body musculoskeletal pain and/or discomfort.

Another interesting comment by one of the technicians was in regard to the general awkwardness of the ladder descending process. His statement was basically that when a person starts to descend the ladder, the process can be made more awkward by the added fact that it may not always be possible to see where their feet at all times in relation to the location of the ladder rungs. During these times, it can be easy to misjudge the distance each foot has to move down to the next ladder rung below until the climber gets into a steady rhythm of the descent process. This means that the climber may have to go more by feel than by vision at times, and that they might be searching for the next ladder rung below with their ankle extending to a significant degree with their toes pointing downward, which may not be an ideal posture for the foot as it absorbs all of the forces involved with the ladder descent process. Also, a single misstep during the descent could contribute to a potential fall situation.

Regarding hand placement on ladder rungs or stiles, one of the technicians in the field stated that some technicians tend to climb up or down with their hands positioned on the ladder stiles instead of the ladder rungs. According to him, either way of performing this activity is fine as long as the individual maintains three points of contact with the ladder at all times. It seems to
be more a factor of personal preference rather than a rule that a person must climb only with their hands on the rungs of the ladder, but it could also be attributed to musculoskeletal discomfort that occurs when repeatedly performing the same forceful gripping motions which creates a musculoskeletal disorder risk factor for the hands, wrists, and forearms over a period of time. This means that some technicians may switch back and forth between a pronated hand posture of grasping the ladder rungs and the semi-prone posture of gripping the ladder stiles to temporarily alleviate the musculoskeletal discomfort that they are experiencing while climbing wind turbine ladders. One technician also noted that when a person is climbing it would be a good idea for them to try to use their whole body to propel themselves up the ladder. Another technician mentioned that having a good pair of climbing gloves is essential because there could be oil, dirt, debris, sharp edges, and other potential hazards on the ladder that you would not want to be exposed to while climbing without gloves. He emphasized that the ladders are not always clean and that it could be both unsanitary and potentially unsafe to be climbing without the use of appropriate gloves. This makes sense because the ladders are being climbed on by people wearing work boots that they probably did not clean off before starting to climb the ladder, and most of these wind turbine towers are out in the country, so technicians would likely have to walk on the ground through mud, dirt, rocks, sand, and snow, before reaching the tower and beginning to climb the ladder. In addition, there is potential for oil or other machine-based fluids dripping down the ladder from the nacelle area if there is any kind of leak in one of the fluid reservoirs located up in the nacelle/turbine area. Another technician stated that climbing up the ladder is very similar to performing a kind of vertical crawling motion. The technician added that when climbing back down the ladder, many people tend to lean back on their safety equipment and safety harness as they descend. The amount they lean back may vary depending
on the type of equipment they are using (harness, ladder safety system, and ladder safety system attachment. There are two main types of ladder fall protection systems currently in use. The fixed rail attachment system, also known as a “Glide-Lok” device and the steel cable attachment system, also known as a “Lad-Saf” device. According to the technicians interviewed in person, the fixed rail “Glide-Lok” system seems potentially safer and sturdier to them. The fixed-rail ladder safety system attachment glides up and down the rail running up and down the middle of the ladder and in the event that they were to lose their footing and fall, the fixed rail ladder safety system attachment will catch them almost immediately and stop them from falling any further.

The steel cable system on the other hand works very much in the same manner, except for the fact that the steel cable is apt to flex and move several inches in any direction in which it is forcefully pulled. This type of system will also immediately activate to catch a falling climber; however, this type of system might not catch them with the same apparent strength and rigidity provided by a fixed rail ladder safety system. In the event of a fall using the steel cable system, the cable would likely flex several inches away from the ladder by in whichever direction it is forcefully pulled. Also, the steel cable system would not seem to support the climber with the same apparent strength and rigidity while ascending and descending the ladder because of the tendency for the steel cable to flex and move during the climbing activity. Climbers may prefer either system and it would likely depend on which systems they have been exposed to or have grown accustomed to in the wind turbine environments which they work. According to several of the technicians who were asked about their personal preferences, the fixed rail seems to be safer and provide a more rigid physical support system for the climber.

**Repetition.** The interviewed technicians indicated that for some projects they may climb up five to seven turbines per day. This would be considered a recurrent activity for several days
in row, or even for several weeks at a time (working 60 to 80-hour weeks), making the repetition involved with ascending and descending wind turbine tower ladders a substantial risk factor for musculoskeletal disorders throughout multiple areas of the body. This list of impacted areas of the body that they specified included the neck, back, hips, knees, ankles, shoulders, elbows, wrists, and hands. The activity of climbing is also very repetitious in where a climber performs the same types of cyclical movements to ascend and descend the vertical ladder of the wind turbine.

**Duration.** The analyzed technicians freely provided enlightening comments related to musculoskeletal disorder conditions which interfere with the average working lifespan of a wind turbine maintenance technician. Their belief is that the average technician working in the industry today has a working life of approximately seven to ten years in the industry as a wind turbine maintenance technician. They provided three specific occupational health and musculoskeletal disorder related reasons for this phenomenon. The first reason is that the knees of an average technician will be unable to perform the regular duties of the job after approximately seven to ten years due to the likelihood of a musculoskeletal disorder type overuse-based injury occurring in one or both knees. The second reason is that technicians will typically get injured in another way that precludes their ability to climb the towers anymore. The third reason that they gave is that most technicians will be burned-out and exhausted in seven to ten years from being forced to work so hard during their career. They said that many turbine technicians regularly work 60-80 hours per week which is a duration-based risk factor that can lead to burnout both mentally and physically as well as increase the risk for musculoskeletal disorders because there is often only limited time to rest and recover between jobs or shifts. During certain projects, they may have to climb five to seven turbines per day for several days in
a row and for numerous weeks at a time. As mentioned previously, they may not have a day off for excessively cold, excessively hot, or inclement weather unless there is lightning in the area. If there is lightning in the area, then this condition will necessitate that they discontinue whatever they are doing and quickly descend the ladder to get back to ground level outside the tower to take shelter in a vehicle nearby. Once the lightning clears the area, the technician will then have to climb all the way back up the tower to resume whatever activities he/she was working on previously and work until the activity is completed, which could make for an excessively long workday. There is also the added factor of commuting to/from the job site which takes up quite a bit of time for many technicians because they have to drive to and from the windfarm where the turbines are located. Oftentimes, windfarms are located in remote areas that may take an excessively long time to commute to/from each day, thus decreasing the overall amount of time available for rest and recuperation between work days or shifts.

**Vibration.** While taking a rest break from climbing a wind turbine ladder, one of the technicians indicated that he occasionally felt whole body vibration during the ladder climbing activity. Another technician noted that the top of the tower and the nacelle area has a tendency to move around and oscillate slightly in the wind to a subtle, yet potentially bothersome degree thus creating a sensation similar to motion sickness. This might be more noticeable and troublesome to individuals who may be susceptible to motion sickness type disorders.

**Static loading.** The interviewed technicians reported potential static loading concerns that occur at times when they are carrying an external load of tools, parts, or equipment. This phenomenon occurs if the weight of the external carried load is not centered or positioned correctly or if the load shifts while climbing. If this occurs, then the climber may notice discomfort in the hips, knees, and the side of the body that is carrying the majority of the weight
of the load which is a static loading related risk factor. Another potential static loading concern is when the wind turbine technicians work on their knees for long periods of time without changing working positions. Working while kneeling occurs frequently as a result of the way that the nacelle and the turbine is commonly constructed as well as the way that certain maintenance tasks must be performed. The interviewed technicians had several brief comments related to this concern. The technicians also reported numbness of the legs and feet after working for long periods of time while kneeling. The technicians reported that they wear kneepads, but that these do not completely prevent knee discomfort and or injury. Additionally, although the technicians did not specifically identify the concern of resting on the ladder as being a possible source of static loading, it could be a potential concern in regards to static loading of the upper and lower extremities, especially the forearms/hands grasping the rungs, and feet which bear the weight of the body while constantly contacting the rungs of the ladder.

**Temperature extremes.** According to discussions with wind turbine technicians who work in the upper Midwest where it tends to be very cold during the winter, they are still working full-time to keep the turbines running during the winter. Some wind turbine technicians reported in the survey that they may tend to be a little less busy in the winter months than during the summer as is indicated in Question 18 of the survey. However, the assessed wind turbine technicians openly stated that they are busy during the winter and rarely have a day off because extremely cold or inclement weather. For instance, it was reported that only one time in the last three years did they have a day off due to it being too cold to work. The assessed technicians freely provided several examples of working in extremely cold environmental temperatures. For instance, the technicians relayed an experience which even at -40° F, their employer still demanded that the work should continue and the employees should persist working outside
servicing and repairing the turbines in order to bring such back online. There were also other examples of the technicians working in -38° F when the wind was blowing at a constant 10mph to 15mph. The most extreme example of the extreme cold temperature working conditions was an example provided in which the technicians were working on a day in which it was -55° F with the wind blowing 20 miles per hour or more.

Additionally, the interviewed technicians reported that when it is very cold outside, it is usually even colder inside the wind turbine because the heavy steel shell of the turbine tower radiates the cold. According to one technician, this phenomenon can feel like working inside a refrigerator or freezer because the turbine tower retains and radiates cold temperatures. When it is cold outside, the wind turbine ladder rungs and stiles pull hand heat right through the technicians’ climbing gloves. This creates a cold temperature extremes risk factor for the technician’s hands, fingers, and wrists. Additionally, this condition of the ladder being so cold, also would likely affect the feet and toes. Further, these extreme cold temperature conditions could create a risk factor for frostbite of both the upper and lower extremities. The technicians also reported that in the winter when it is cold, it would be very important to know how to pace oneself because if they climb up the ladder at a normal pace in which they would regularly work up a sweat, then by the time they reach the top of the tower they will be wet and will start to become incredibly cold due to the dampened clothing exceptionally quickly, potentially leading to hypothermia. During the winter months, the wind turbine technicians freely expressed that they were quite often forced to work in extremely cold conditions for extended periods of time in order to service the turbines and keep such running constantly year-round. This is an indication of a risk factor in regards to exposure of wind turbine technicians to cold temperature extremes. Conversely, the wind turbine technicians also stated that they are additionally exposed to
extreme heat conditions. The interviewed technicians reported that in the summertime, the extreme temperature conditions within the work environment of the tower can become unbearably or ever dangerously hot. Again, this is because the steel shell of the turbine tower retains and radiates heat while amplifying the internal temperatures of the wind turbine working environment. According to several of the technicians, on certain days it can feel like working inside a hot oven. The climbing activity in itself is enough to potentially overheat a worker. With the additional temperature-related stress of the radiant heat emanating from the walls of the turbine itself, this situation may contribute to heat stress conditions, thereby inducing excessive sweating and hyperthermia which could then lead to potential exhaustion and heat stroke. If a wind turbine maintenance technician were to lose consciousness due to either heat-related fatigue or cold stress while at any of the upper level platform decks or the nacelle, it would cause quite an unfavorable situation and would likely necessitate a rescue operation.

**Goal #3.** - Compare the quantified tower maintenance employee risk factors against commonly-used ergonomic risk assessment tools.

**The Great American Insurance Company Ergonomics Task Analysis Worksheet**

The Great American Insurance Company Ergonomics Task Analysis Worksheet (which is located in Appendix A) was utilized to analyze the recorded videos of technicians climbing wind turbine ladders. The technicians were analyzed as a whole group using the Ergonomics Task Analysis Worksheet because they were all performing the exact same type of task. Further, the postures and movements they each exhibited during the wind turbine ladder climbing activity were exceptionally similar. Additionally, the wind turbine ladder climbing activity took place on the same type of wind turbine ladder in the same type of wind turbine environment for each of the subjects who were analyzed.
The Great American Insurance Company Ergonomics Task Analysis Worksheet classifies different risk factors into 3 distinct categories of risk. The risk factors analyzed include repetition, posture, vibration, reach/proper height, force, static loading and fatigue, pressure/contact stress/repeated impacts, lifting and materials handling, and environmental stressors. The classifications for each different risk factor type are divided into three distinct categories in order of risk severity. The three categories are arranged by level of risk severity from the lowest risk category which is identified as Ideal, to the middle category identified as Warning Level–Monitor, and finally the highest level of risk which is referred to as Take Action.

**Repetition.** The Ergonomics Task Analysis worksheet begins with the risk factor of repetition. For the category of repetition, an Ideal situation would be classified as having no repetitive hand or arm motions. A Warning Level situation would be categorized as a task containing repetitive hand or arm motions with cycle times of 30-60 seconds. A Warning level situation would be categorized as repetitive hand or arm motions with cycle time of less than 30 seconds. Upon a review of the collected video data of the wind turbine climbing activity, it is apparent that the cycle times involved in the climbing activity are extremely repetitive and would be characterized at the Take Action level of risk. This is because the cycle time involved with each step of the activity of climbing wind turbine ladders is far less than 30 seconds for each repeated cycle of motion involved with both climbing up and down the wind turbine ladder.

**Posture.** There are three areas of postural concerns that would apply to the wind turbine climbing activity as classified by the Great American Insurance Ergonomics Task Analysis Worksheet. The first category of posture risk that applies to the wind turbine ladder climbing activity is head/neck risk factor issues. An Ideal situation would be that the head and neck are upright and straight during the work activity. A Warning Level – Monitor risk level would be
considered for a work situation where the head and neck are often flexed forward more than 1° but less than 20°. A risk level of Take Action would be triggered if the head and neck was flexed forward more than 20° for greater than 3 hours per day. It was observed that all of the climbers consistently flexed their head/neck forward during the wind turbine ladder climbing activity. This was especially apparent during the ladder descent activity, which would be a Warning Level – Monitor level of risk. It was also observed that all of the climbers were consistently extending their head/neck backwards to a significant degree while climbing the ladder and looking upwards. Often, the climbers extended their head and neck backwards at an angle greater than 10° while climbing which would be classified as a Take Action level risk.

The second general category of postural risk concerns the hands. It was observed that all of the climbers consistently rotate their hands more than 20° while climbing up and down the ladders which is considered a Take Action level risk factor. The third postural concern is related to the wrists. An Ideal position would be that the wrists are straight. In ascending and descending the ladders it was observed that the climbers bent their wrists more than 30 times per minute or bent more than 20° which would be a Take Action level risk factor. Additionally, it was observed that the climbers move their wrists sideways more than 30 times per minute or more than 20° which is also a Take Action level risk factor.

**Vibration.** During personal observation of the climbing activity as well as during playback of the videos it could not be determined whether vibration should be categorized as a risk factor in the wind turbine climbing activity. However, during informal discussions, the subjects noted that they did experience occasional whole-body vibration during the ladder climbing activity, which would be a Warning Level – Monitor risk factor.
**Reach / proper height.** An ideal position for working would be performed with the elbows at 90° or slightly above or below elbow level. A Take Action level risk factor would be considered as having the arms forward more than 45° or constantly maintained outside of the ideal position for more than three hours per day. The technicians recorded climbing constantly had the arms out of the ideal working position while ascending and descending wind turbine ladders which would be a Take Action risk factor. Another Take Action level risk factor that applied to the recorded technicians was that they regularly had their elbows flexed more than 25% above or below the ideal position. An ideal position in the risk category of twisting, reaching, or bending would be no twisting, reaching, or significant flexing. The recorded climbers did flex and reach to a significant degree and on occasion while climbing wind turbine ladders which could be categorized as a Take action level for bending/reaching to the side more than 20°.

**Force.** In regards to the observed wind turbine ladder climbing activities, it was readily apparent that force was an issue the technicians have to deal with any time that they are climbing the vertical ladders of wind turbines. The Ergonomics Task Analysis Worksheet however does not recognize the exact types of force-related actions involved with climbing wind turbine ladders. For instance, an Ideal amount of force would be categorized as objects which are regularly lifted by the hand in the workplace are less than one pound in weight. The Take Action level however would be triggered for this category if the objects lifted by hand are more than one pound or are highly repetitive (more than 20 times per hour). Since the climbers are supporting and lifting/carrying their own body weight (some of which is regularly lifted or pulled by the hands more than 20 times per hour during the climbing activity) while climbing up and down 300+ foot vertical wind turbine ladders, this would qualify as a Take Action level activity.
Additionally, while climbing wind turbine ladders, a hand power grip of the rungs of the ladder is frequently and forcefully used both to climb up the ladder and to provide balance. The observed climbing activities undoubtedly contained forceful power grip situations that would certainly trigger the Take Action level for power grip which is that a power grip is used with more than 10 pounds of force, or the forearm rotation force is more than five pounds. In the case of climbing wind turbine ladders, it would likely be both of those factors. With regard to force risk factors, according to the Great American Insurance Ergonomics Task Analysis Worksheet, it is a Warning Level – Monitor risk factor if gloves are needed for the activity. If gloves are needed for the task but such fit poorly, then it would be considered a Take Action level risk factor. The great majority of wind turbine technicians tend to wear gloves during the wind turbine ladder climbing activity due to the inherent hand-associated hazards involved with climbing wind turbine ladders, but the gloves do seem to be sized correctly and fit well for the technicians.

**Static loading and fatigue.** According to the Great American Insurance Ergonomics Task Analysis Worksheet, tasks that use the same muscles or motions for long durations (six seconds or more at one time), as well as repetition where more than 50% of the task is repetitive increase the likelihood of fatigue. The example given for a Take Action risk factor related to duration consists of a tool or object being held for more than 10 seconds in a constant position. The Take Action level example for Repetition includes activities where more than 50% of the task is repetitive. Climbing wind turbine ladders may be considered a task that requires performing exactly the same repetitious climbing motion each step of the way to reach the top of the ladder. This could also be said for the descending activity, where the same basic cycle of motions is repeated to safely descend back to the ground level. It could then be said that the
wind turbine climbing activities were observed to be beyond the Take Action level of 50% task repetition.

**Pressure / contact stress / repeated impacts.** According to the Great American Insurance Ergonomics Task Analysis Worksheet, the Ideal situation regarding Pressure/Contact Stress/Repeated Impacts would be that there is no contact or impact stress from tools, objects in the workplace, or the workstation pressing against the hands or the body. A Warning Level – Monitor risk factor for this category is stated as occasional and minimal pressure or impact on the hands or on the body and/or that the hand, knee, or other body part is used as a hammer less than two hours per day. The Take Action level for the risk factor of Pressure/Contact Stress/Repeated Impacts is stated as constant pressure or impact on the hands or body and/or that the hand, knee, or other body part is used as a hammer more than two hours per day. The choice for this category that appears to match the observed climbing activities performed by wind turbine technicians is the Take Action level because the wind turbine ladder climbing activity places a constant or near constant pressure on the hand and feet. In addition, ladder ascending/descending activities both appear to subject the climbers to consistent and repeated impact forces on the hands and feet as well as the associated muscles, joints, and tendons of the upper and lower extremities.

**Lifting and materials handling.** Although this category of the Great American Insurance Ergonomics Task Analysis Worksheet speaks exclusively of the lifting and lowering or pushing and pulling of objects or materials separate and distinct from the human body, it is still potentially applicable to the observed ladder climbing activities. The Take Action level for lifting/lowering materials is stated as constant lifting and/or lowering (more than 20 times per hour). In addition, the Take Action level for pushing or pulling materials is stated as high force
being required to push or pull materials. Technicians performing wind turbine ladder climbing activities appear to be exerting high amounts of force when pushing and pulling their own body weight while fighting the forces of gravity during the vertical ladder climbing activity. It could also be said that technicians exert a great deal of effort by lifting their full body weight up each step or rung while ascending the ladder (at cycle rates that greatly exceed 20 times per hour during the climbing activity). Further, the technicians also have to carry the additional weights of their climbing harness and safety equipment as well as any portable tools or equipment which are manually carried up to the nacelle for turbine maintenance and repair activities.

**Environment.** The five potential environmental risk factors listed on the Great American Insurance Ergonomics Task Analysis Worksheet include Work Pace, Lighting, Temperature, Noise, and Floor Surface. An Ideal pace for working would be one where the worker has adequate control over the pace of the work. A working situation where the worker only has a certain amount of control over the pace of work would be rated as a Warning Level – Monitor risk factor, and a work situation where the worker exhibits no control over the pace of work would be considered a Take Action risk level. Wind turbine technicians appear to exhibit a certain amount of independence and control over the pace of work, but like most any other job, they do have deadlines and timeline objectives to meet when performing maintenance or repair activities. Generally, they are asked by their employers to perform servicing and maintenance activities as quickly as possible in order to maintain the wind turbines in a near-continuous operational status. In this way, the technicians appear to only exhibit a limited amount of control over the pace of their work.

In regards to lighting and visibility within the work environment, it was observed to be inadequate due to it being slightly dark and thus is considered a Warning Level – Monitor risk
factor. As for temperature concerns, it was noted in informal conversations with technicians that wind turbine towers regularly become uncomfortably hot during the summer months and significantly cold during the winter months. This would then qualify as a Take Action level risk factor in regards to temperature-related concerns. With regard to the noise level of the wind turbine work environment, it was quickly apparent that the environment had a potential to be loud and noisy whenever there are activities taking place in the tower. This is because the cylindrical steel shell of the turbine tower tends to echo and reverberate with any noise that is made inside the tower. The noise reverberation was not so loud as to make carrying on a conversation impossible, although voices might have to be raised to a high level. Overall, the observed work environment would qualify as a Warning Level – Monitor in regards to environmental noise.

Floor surface is the final environmental concern which is listed on the Great American Insurance Ergonomics Task Analysis Worksheet. There are two distinct types of concerns related to floor surface that potentially apply to the observed working activities which include traction and flooring surfaces that potentially contribute additional stresses placed on the back and/or legs of workers. The traction of the rungs of wind turbine ladders were evaluated as ranging from providing a good level of traction (Ideal), to slightly slippery (Warning Level), to moderately slippery (Take Action). The quality of traction for walking/climbing surfaces depended on the condition of each individual ladder inside each individual wind turbine. If the ladders and the turbine floors are well maintained so as to keep the ladder clean and free from dirt, mud, grease, oil, and other buildup or debris, then the ladder and the floor will likely provide an acceptable level of traction. Unfortunately, even under the best conditions, the rungs of wind turbine ladders are typically very slender. The rungs of the ladders observed in this
study were square in shape and approximately one inch wide on each side, which may not allow for adequate or satisfactory traction. The next item in regards to floor surface has to do with the matter of stress relief or added stress on the back and the legs of the person standing on the surface. An Ideal condition would be flooring that is sufficiently padded as to relieve stress on the back and/or legs of the person standing on it. However, a would be when flooring contributes slightly to the additional overall stress placed upon a back and/or legs of the person standing on it, this would be considered a Warning Level – Monitor risk factor. And if the flooring were to contribute moderate stress on the back and legs, it would be considered a Take Action level risk factor. In this case, the rungs of the ladder would be considered the flooring surface which technicians stand upon for periods of time while performing ladder climbing activities. The ladder rungs may contribute to a moderate amount of stress on the back and the legs while a person stands or moves around on this working surface, therefore this aspect of the work environment would fall into the category of a Take Action level risk factor.
Chapter V: Conclusions and Recommendations

Company XYZ is concerned that maintenance technicians who frequently climb the internal ladders of power generating wind turbine towers throughout their daily work-shift are placed at risk of experiencing upper as well as lower extremity MSDs. Thus, the purpose of this study is to identify the extent to which musculoskeletal disorders may occur among maintenance employees who are required to frequently climb wind power generation towers throughout their daily work-shift. One of the goals of this study was to survey wind turbine power generation maintenance employees to determine the extent that they are experiencing various musculoskeletal disorder symptoms. A second goal of this study was to perform ergonomic assessments of ladder climbing activities among wind turbine maintenance personnel in order to quantify the extent of force, posture, repetition, duration, vibration, and temperature-related risk factors to which the technicians are typically exposed. A third goal of this study was to compare the quantified tower maintenance employee risk factors against commonly-used ergonomic risk assessment tools.

The goals of this study were achieved by the utilization of the various procedures outlined and explained in the methodology described in Chapter III and implemented in Chapter IV. In order to study the ergonomic factors involved with the ladder climbing activities of maintenance technicians in wind turbine towers, the research was initiated by measuring and assessing the workplace/work environment. Visual information was gathered and assessed. Following observation and analysis of the climbing activity, potential work-related hazards, risks, and adverse conditions were identified. Video and still pictures of maintenance technicians performing the essential activity (ascending and descending wind turbine ladders) was recorded, analyzed, and utilized as part of the overall assessment. During later video
playback, measurements of angles and body positions (postures and movements) were further assessed using a manual goniometer. The Great American Insurance Company Task Analysis Worksheet was utilized to perform further ergonomic assessment of the work activity during playback of the video recordings. A detailed multi-question online survey was utilized to assess many different aspects and risks specific to the wind turbine technician occupation. The online survey also included a symptom survey which provided additional necessary and insightful data related to MSD symptoms reported by the technicians. There were approximately 30 individual respondents to the survey. The study made a concerted effort to inquire about MSD symptoms and conditions that maintenance technicians are currently experiencing as well as those that they have experienced in the past. The survey results were evaluated to assess and identify the types, prevalence, and severity of work-related musculoskeletal disorders experienced by the study participants as a result of performing wind turbine ladder climbing activities.

Additional information and insight into the occupational working conditions of wind turbine technicians was gathered during the review of on-site video recordings and informal discussions between the researcher and the subjects. The survey responses were analyzed and the significant points of the survey findings were discussed in detail in Chapter IV. This was followed by an in-depth ergonomic analysis of the video recordings of three separate subjects performing wind turbine ladder climbing (ascending and descending) activities. A summary of observed adverse postures, forceful repeated movements, and other risk factors was listed after the analysis of each subject. This was followed by a section which discussed the climbing activity and was supplemented by comments gathered from the in-person interviews with the study subjects. Finally, the Great American Insurance Company Task Analysis Worksheet was utilized to further assess the documented ladder climbing activities.
Conclusions

The following is a list of conclusions drawn from the study:

- The wind turbine ladder climbing activity is very strenuous. Over 80% of the respondents (82.76%) rated the ladder climbing activity as at least an 8 out of possible 10 for physical exertion, and of those, 72.42% rated the ladder climbing activity as either a 9 out of 10 or a 10 out of 10 in reference to physical exertion. This makes it apparent that the amount of physical exertion required to climb wind turbine ladders places wind turbine technicians at significant risk of incurring a musculoskeletal disorder.

- Of the survey respondents, 85.71% reported experiencing symptoms such as pain, discomfort, or a decrease in ability or range of motion (generalized musculoskeletal disorder symptoms) which they attributed to ladder climbing activities (ascending/descending wind turbine ladders). Respondents reported experiencing these symptoms both during regular working hours and outside of working hours (meaning that the respondents are experiencing the pain or discomfort symptoms while they are at work and then they continue to experience these symptoms after leaving work). Additionally, over 80% of the respondents (82.14%) reported experiencing work-related pain, discomfort, or a decrease in ability or range of motion (generalized MSD symptoms) that lasted for three or more days. This three-day duration of symptoms is another key indicator that these employees are likely being affected by MSDs or at least the onset of MSDs.

- The ladder climbing activity entails forceful movements which were readily observable in the analysis of recorded ladder climbing activities. An analysis of the
survey responses agrees with this finding. When the survey respondents were asked to rate the ergonomic risk factor of force, rating on a 10-point scale (where 10 = force demands are at or above their maximum force abilities and may at times result in pain and/or discomfort), 85.19% of the respondents rated force as an 8, 9, or 10 out of 10. From an analysis of the survey responses, it is apparent that force is a significant risk factor for wind turbine technicians who are climbing wind turbine ladders.

- The ladder climbing activity requires unergonomic postures which were readily observable in the analysis of the ladder climbing activities. An analysis of the survey responses agrees with this finding. When the survey respondents were asked to rate the ergonomic risk factor of posture, rating on a 10-point scale (where 10 = postures are awkward and/or uncomfortable and frequently result in pain and/or discomfort), 81.49% of the respondents rated posture as a 9 or a 10 out of 10. As a result of analyzing the survey responses, it appears that posture is a significant risk factor for wind turbine technicians who are climbing wind turbine ladders.

- The ladder climbing activity involves exceptionally repetitive movements which were readily observable in the analysis of the ladder climbing activities. An analysis of the survey responses agrees with this finding. When the survey respondents were asked to rate the ergonomic risk factor of repetition, rating on a 10-point scale (where 10 = repetitions are excessive and result in pain and/or discomfort), 85.19% of the respondents rated repetition as an 8, 9, or a 10 out of 10. From analyzing the survey responses, it is quite obvious that repetition is a significant risk factor for technicians who are climbing wind turbine ladders.
• Wind turbine technicians experience moderate risk from duration-based risk factors and this was made apparent from the responses gathered from multiple survey questions. 64.51% work more than 40 hours per week, 45.16% reported working 50-60 hours per week on a regular basis. Over 90% of respondents (93.3%) reported working 12 or more hours per day when operations are busy and 36.7% reported working up to 16-hour days when operations were at the busiest. Over 80% of respondents (83%) reported regularly working overtime (over 40 hours per week), while 32% reported working an extra 10 hours per week on a regular basis, and 28% reported working an extra 20 hours per week on a regular basis. These statistics from the survey responses indicate that the employees are also exposed to the risk factor of duration. Technicians seemingly do not have a chance to avoid the risk factors force, posture, repetition, duration, contact stress, static loading, and hot/cold temperature extremes because they generally work long hours year-round, because the turbines need to continue producing energy from the wind. Also in regards to the ergonomic risk factor of duration, when the participants were asked to rate their exposure to duration-based risk factors, (where 10 = duration of work times are excessive and frequently result in fatigue and/or discomfort), 81.48% of the respondents rated duration as a 7, 8, or 9 out of 10. From analyzing the survey responses, there is reason to assert that duration is a problematic risk factor for technicians who are routinely required to climb wind turbine ladders.

• The ladder climbing activity contains a moderate amount of contact stress. When the survey respondents were asked to rate the ergonomic risk factor of contact stress on a 10-point scale (where 10 = contact stress situations are excessive or frequent and tend
to result in discomfort and/or pain), 55.56% of the respondents rated contact stress as a 7, 8, or 9 out of 10. From the survey responses, it is apparent that contact stress is a problematic risk factor for technicians who are required to climb wind turbine ladders.

- The ladder climbing activity is contains a substantial amount of static loading. When the survey respondents were asked to rate the ergonomic risk factor of static loading on a 10-point scale (where 10 = static-loading forces are excessively demanding and cause pain and/or discomfort), 81.48% of the respondents rated static loading as an 8, 9, or 10 out of 10. From analyzing the survey responses, it is evident that static loading is a substantial risk factor for technicians who are required to climb wind turbine ladders.

- Technicians working and climbing ladders in the wind turbine environment are subject to substantial amounts of cold stress (cold temperature extremes risk factor). When the survey respondents were asked to rate the ergonomic risk factor cold temperature extremes, rating on a 10-point scale (where 10 = cold stress situations are excessive and frequently cause whole body cooling or localized cooling of the hands and/or feet which frequently results in discomfort and/or pain), 77.78% of the respondents rated cold temperature extremes as an 8, 9, or 10 out of 10. When the participants were asked about the coldest environmental temperatures that they have been exposed to while working in wind turbine environments, the two most common responses were -10°F and -20°F. The coldest temperature responses gathered were between -24°F and -41°F. Interviews and conversations with wind turbine technicians regarding cold temperature extremes further supported the data gathered
from these survey responses, which made it apparent that cold temperature extremes are a significant and problematic risk factor for wind turbine technicians who are required to climb wind turbine ladders.

- Technicians working and climbing ladders in the wind turbine environment are subject to excessive amounts of heat stress (Hot Temperature Extremes Risk Factor). When the survey respondents were asked to rate the ergonomic risk factor of Hot Temperature Extremes, rating on a 10-point scale (where 10 = Heat Stress Situations are severe and may be resulting in any of the following, including excessive sweating with flushed-red skin, headache, dizziness, noticeable dehydration, lightheadedness, nausea, sickness, or generalized discomfort and/or pain), 81.48% of the respondents rated Hot Temperature Extremes as a 9 or 10 out of 10. When the respondents were asked a follow-up question about what are the hottest environmental temperatures they have been exposed to while working in wind turbine environments, the most common response was 120°F. From analyzing the survey responses, it is quite obvious that Hot Temperature Extremes are a very significant and problematic risk factor for wind turbine technicians performing their job duties and climbing wind turbine ladders, especially given the fact that over 80% of the respondents rated Hot Temperature Extremes as a 9 or a 10 out of 10, which makes it a very prevalent and extreme risk factor.

- In regards to missed work days due to MSD symptoms directly related to the ladder climbing activity, 51.85% of the survey respondents indicated that they had missed work in the past due to MSD symptoms. When those respondents who had missed work days were asked follow-up questions about how many days they had missed in
the last year due to MSD symptoms, 51.15% reported missing three to five days of work and 42.97% had missed six to twelve days due to their symptoms. This means that MSD symptoms produced by the climbing activity are already taking a toll on the workforce and on the quantity of the work that can be completed due to absences. There is likely a production cost related to every missed day of work for each employee as well as a detriment to the company by way of potentially losing the valuable expertise of experienced employees.

- The lower extremities were found to be the area of the body placed at the highest risk for MSDs from the stresses of the climbing activity. The knees were the most common single area of bodily discomfort selected by the survey respondents and it was apparent as to why this was the case based on observations made in the analysis of climbing activities. Further, in regards to the muscular energy utilized in ascending/descending ladders, the respondents reported that on average, their legs exerted the vast majority (83.41%) of the muscular effort required to climb up the ladder.

- In regards to the upper extremities, the shoulders were the most reported upper extremity area of musculoskeletal discomfort symptoms. This was supported by the analysis of the climbing activity in which the shoulders frequently moved to extreme postural angles and also performed frequent and repeated forceful movements.

- Regarding typical working hours and overtime for wind turbine tower technicians, a great majority of respondents (80.65%) regularly work more than eight hours per day. Of those, 61% reported working up to 10 hours per day and 12.91% reported working more than 10 hours per day. Of the respondents to the survey, 93.3% reported
working twelve or more hours per day when operations were busy. A majority of 83% also indicated that they regularly tend to work more than forty hours per week. Additionally, 60% of respondents indicated regularly working 10 to 20 hours of overtime per week. This establishes that technicians frequently work overtime and that when operations are at the busiest, technicians may be occasionally asked to work excessively long shifts. Excessively long shifts and significant amounts of overtime work are likely to cause tiredness and exhaustion, which could then potentially lead to workplace mistakes, accidents, and occupational injuries in the short term, as well as encourage the development of musculoskeletal disorders over the long term.

- Regarding wind turbine technician’s current access to wind turbine elevators, 81.25% of respondents reported that they are regularly forced to use ladders because there is no alternative means of ascending and descending the wind turbine environment besides the ladders. Three-quarters of the survey participants (75%) reported that they must climb five or more times per week because there is no alternative to climbing wind turbine ladders. Approximately 65% of those respondents (65.63%) responded that they must climb 8 or more times per week because there is no alternative to climbing the wind turbine ladders.

- Regarding the future occupational plans of technicians, a large majority of the respondents (80%) reported that they are planning on working another twenty or more years as a wind turbine maintenance technician. Of this group, 46.67% are planning on working thirty or more years as wind turbine technicians. This is an interesting insight into the aspirations and dedication of wind turbine maintenance technicians.
who seemingly desire to work in this occupational field for a considerable amount of time. This data concerning the goals of wind turbine technicians to keep working for many years is especially interesting when combined with the questions regarding wind turbine elevators. All of the survey respondents (100%) indicated that regular access to wind turbine elevators would enable them to continue working in this occupation for many years to come, or for as long as they desire. Additionally, 100% of the survey respondents emphatically indicated that they would prefer wind turbine elevators over other mobility solutions. Moreover, 100% of the participants unanimously agreed that regular and consistent access to wind turbine elevators would increase their daily productivity and efficiency.

- There was a significant percentage of respondents who reported not receiving adequate training in climbing ladders efficiently as well as a percentage of respondents who reported not receiving adequate training in regards to safely ascending and descending wind turbine ladders. All wind turbine technicians should have the opportunity to refresh their training and to learn about new techniques or best industry practices for climbing ladders. They will always need to remain in a state of readiness, just in case any wind turbine mobility solutions were to fail (climb assist or elevators), so that they could successfully manually transport themselves up or down the ladder in an emergency situation.

- The climbing harnesses of the interview subjects was only rated to carry an additional 40 pounds, but many of the survey respondents reported having carried additional weight (tools, equipment, and other items) in excess of 40 pounds. Carrying weight beyond the rated capacity of the climbing harness creates a hazardous situation and is
an unsafe working condition due to the added stress on the harness in the event of a fall-related scenario. Also, carrying this additional weight places additional stresses on the bodies of technicians and thus further exposes them to risk factors such as force and repetition during the climbing activity.

- There are potentially severe fall-related injury risks if technicians do not steadfastly adhere to safe work practices such as maintaining 100% attachment to a fall protection system or remaining tied-off to a fixed object with a fall protection lanyard 100% of the time while they are transitioning to/from the ladder and wherever the potential for fall-related hazards exist. These risks are significantly mitigated by implementing consistent safe work practices such as maintaining attachment to either a ladder safety system or a using a fall protection lanyard to remain tied-off to a fixed attachment point 100% of the time whenever the potential for fall-related hazards exists.

**Recommendations for Engineering Controls**

The following is a list of recommended engineering controls based on the findings and conclusions of the study:

- Install wind turbine elevators. It is believed that the installation of elevators would alleviate most of the MSD symptoms being experienced as expressed by the employees in the survey. Wind turbine elevators would likely make wind turbine technicians more productive on a daily basis and would extend their occupational life on the job which is a win-win for everyone. They also reported that elevators would help them become more productive and efficient. Wind turbine elevators are the safest and most efficient means of reliably transporting technicians to/from the
nacelle and the installation of such would likely help companies to retain valued technician employees as well as increase the occupational employment longevity of the most experienced wind turbine technicians. Additionally, it would remove the dangerous levels of weight carried by technicians as well as the already dangerous forces and postures and repetitive movements that are naturally a part of the ladder climbing (ascending and descending activity). It would help alleviate the problems caused by employee exposure to extreme cold temperatures which could cause hypothermia and extreme heat which could cause heat exhaustion during or after the ladder climbing activity. Wind turbine elevators could also help evacuate an injured or incapacitated employee much more effectively than other methods which involve the use of body harnesses. In the event that it is not possible to install elevators in wind turbines, the next best engineering control recommendation would be to install climb assist or other significant alternative mobility enhancing devices or modes of transportation which reduce the stresses placed on the bodies of technicians.

- Install material and equipment lifting devices in all wind turbine towers to easily transport tools, materials, and equipment to/from the nacelle area.

**Recommendations for Administrative Controls**

The following is a list of recommended administrative controls based on the findings and conclusions of the study:

- From a safety and risk standpoint, as long as employees are required to manually climb wind turbine ladders, it is recommended that employers implement policies which limit the number of hours that an individual is allowed to work per shift and
per week, thereby helping to prevent accidents and decreasing the chances of employees developing MSDs.

- It is recommended that wind turbine technicians receive training on performing warm-up and cool down routines as well as stretching exercises. Management should also implement policies which emphasize the importance of and allow time for the performance of proper warm-up and stretching exercises before any climbing activity is initiated and additional stretching while taking breaks during the climbing activity and that a cool-down routine is implemented to be regularly performed after the climbing activity has been completed. This would help prevent injuries and MSDs, help retain long term and valued employees, help reduce employee turnover, reduce lost time incidents, reduce employee losses, reduce stress on overworked muscles, increase flexibility, enhance range of motion, promote a healthy work environment for all employees, and help promote a healthy lifestyle for employees outside of work.

- It is recommended that employers promote policies in which technicians are made to feel comfortable and are highly encouraged to seek first aid or medical treatment as necessary at the first sign of MSD symptoms, injury, or strain. The technicians need to know that any information they share is completely confidential and will only be utilized to educate and/or create a safer work environment. A properly implemented employee injury management program would reduce insurance costs, reduce lost time incidents, and improve worker morale. This would also help alleviate symptoms and recognize and remediate situations that may be the source or cause of the symptoms before they turn into debilitating MSD conditions. This may also control the costs
associated with injuries and the connected costs of insurance and workers compensation claims. It would also help decrease lost-time injuries and reduce the number of incidents which require OSHA related injury reporting.

- It is recommended that companies need to proactively provide the technicians with access to physical therapy in order to help these employees alleviate or reduce MSD symptoms before such disorders become debilitating lost time injuries.

- It is recommended the technicians be permitted to utilize telemedicine in order to seek immediate doctor’s advice to support successful injury case management. This is especially necessary because wind turbine towers are generally located in remote areas and this practice would allow quick access to doctors offsite.

- It is recommended that employers institute applicable policies that promote a positive work environment where employees feel comfortable to freely report any MSD symptoms or any other injuries or anything else that is negative (close calls, mishaps, accidents, etc.) with total confidence, confidentiality, and without any fear of any possible negative repercussions that would endanger their current or future employment prospects. If an employee suspects in any way that reporting an injury or MSD symptom would compromise his/her continued employment, then he/she will likely not report anything but the most severe and obvious events that are witnessed by others.

- It is recommended that training on wind turbine ladders should be mandatory for all technicians. Wind turbine technicians should have annual or biannual verification of ladder climbing related training, and re-training as necessary in order to maintain a significant degree of ladder climbing ability with attention to safe and ergonomic
work practices. Suggestions made for additional training by the surveyed technicians include providing them with extra training time wherein they can gain more experience and receive training on different turbines with different scenarios. This form of training would be especially helpful and essential for new employees.

- It is recommended that employers implement a safe work practice of always requiring the technicians to work in teams of two or more persons, so that no individual technician is ever working alone for an extended period of time out of sight/hearing range of the other technician(s) in the crew. It would also be recommended that employers establish plans for various different types of emergency situations related to the occupation of wind turbine technicians and implement a regular schedule of events where employees have the opportunity to practice various different types of emergency rescue scenarios. Further, employers should implement a reliable system of radio communications between technician teams and a centralized base of operations. This would be expected to increase communication across teams of employees and also streamline the task of summoning emergency assistance to the correct location in a timely fashion.

- Employers need to pay attention to the weight of the tools and equipment that employees are expected or allowed to manually carry up/down the ladder and take with them up to the nacelle. Employers should implement rules about how much additional weight the employees are allowed to carry while climbing ladders (ideally, they should carry no extra weight) and enforce these policies fairly by providing an alternative means of transporting objects, tools, and equipment, to/from the nacelle area.
• Climbing harnesses, pelican hooks and lanyards, and ladder safety system attachment devices should all be inspected daily, and before each use. They should also be submitted to a very thorough annual inspection to be performed by a certified 3rd party who will inspect and test the climbing gear.

• All employees should be trained to thoroughly inspect their personal climbing equipment. This training should be verified annually.

• All employees should be provided a reasonable budget to purchase a climbing harness to be used while climbing wind turbine ladders and working inside wind turbine environments. These devices should be selected by the individual to maintain correct fit and optimal comfort.

• All employees should be given an annual budget to purchase a set of knee pads to be used while climbing wind turbine ladders and working inside wind turbine environments. These knee pads should be selected by the individual to maintain correct fit and optimal comfort.

• All employees should be given an annual budget to purchase a set of boots and a set of insoles to be used while climbing wind turbine ladders and working inside wind turbine environments. These boots should be selected by the individual to maintain correct fit and optimal comfort.

• All employees should be given a semi-annual budget to purchase a set of gloves to be used while climbing wind turbine ladders and working inside wind turbine environments. These gloves should be selected by the individual to maintain correct fit and optimal comfort. Also, since hand grip is such a critical safety and comfort
issue, a team of technicians should be assembled to test/verify the best forms of
gloves that should be worn for ladder climbing activities.

- All employees should be given a semi-annual budget to purchase a set of safety
glasses to be used while climbing wind turbine ladders and working inside wind
turbine environments. These safety glasses should be selected by the individual to
maintain correct fit and optimal comfort.

- In general, any personal protective equipment purchased by the employer to be worn
by the employees should go through an employer/employee committee approval
process. In this process, both management and the employees would be involved in
the testing of personal protective equipment before purchases are made in bulk, so
that there is agreement and buy-in from both management and employees.

- To reduce the potentially severe fall-related injury risks to technicians while they are
transitioning to/from the ladder, employers should implement policies which
significantly mitigate these risks. This can be accomplished by implementing strict
company guidelines and procedures which emphasize the importance of employees
consistently performing all regular safe work practices all of the time and always
maintaining 100% tie-off to a ladder safety system or another harness/lanyard
attachment point 100% of the time whenever there is a potential for fall-related
hazards.

- For those management and related decision-making personnel who are hesitant or
resistant to the idea of spending company funds on the installation and maintenance
of wind turbine elevators, it would be strongly encouraged that they take part in a
wind turbine ladder climbing activity (ascending and descending). It would be highly
recommended that they experience the activity first-hand for a sufficient period of


time (anywhere between several hours to several days-time) as this would lead to an

enriched perspective on the issue by increasing their overall understanding of the

vertical wind turbine ladder climbing activity as well as an enhanced comprehension

of the recurrent stresses and severe impacts that are placed upon the muscles, joints,

tendons, and ligaments of personnel who are employed to service, maintain, and

repair the wind turbines. Such an activity may also improve relations between

management and employees.

Areas of Further Research

The following is a list of suggested areas of further research:

• Employers should perform an in-depth review of the history and nature of employee

injuries including MSDs. Contractor injuries could also be studied to determine

injuries and MSDs if wind turbines are being serviced in part or in whole by outside

contractors.

• Although a properly implemented policy/program of 100% tie-off would mean that

there would only be a slight chance of incurring potentially severe fall-related injury

risks to technicians while they are transitioning to/from the ladder, it is still an

important and worthy area of study. The wind turbine environment and the wind

turbine ladder climbing activity are natural candidates for the development of

occupational safety advancements and improvements related to fall protection

technology and devices, thus further study into novel/innovative fall protection

technologies and advanced methods of fall prevention would always be welcome.

Also, further study may also be warranted on the related topic of employee
compliance with company policies and certain fall protection and fall prevention safe work practice guidelines (i.e. 100% tie-off at all times when there is a potential fall hazard). These areas of study could be important and beneficial to the wind industry as a whole and may have implications on other industries in which falls from height and falls from ladders present an undeniable risk.

- Further research should be conducted on the topic of fall-arrest communication alert systems and future technologies which would let employers know precisely when and where an employee may have sustained a fall in order to immediately recognize such emergency situations and rapidly summon the necessary emergency assistance personnel/equipment to the scene.

- It would be encouraging to create an ergonomic task analysis worksheet or similar types of analysis tools that included sections which were readily applicable to a wider variety of different workplace movements and types of activities such as walking up/down inclines, walking over rough terrain, or climbing stairs, and climbing up/down ladders. In this respect, supplementary sections dedicated to an optional in-depth analysis of the lower extremities (hip and knee movements) would be especially helpful.

- Wind turbine engineering/design organizations should consider taking anthropometric data into account during the design of wind turbine elevators and climb assist devices. Anthropometric data could also be of use in the design of wind turbine ladders to possibly make the climbing activity more ergonomically acceptable. Anthropometrics could also be incorporated into the overall design of wind turbine
nacelle areas with a focus on making repair and maintenance tasks more ergonomically acceptable.

- Research should be performed on the cardiopulmonary and cardiovascular effects of climbing wind turbine ladders.
- Nationwide statistics on MSDs and other injuries incurred by wind turbine maintenance technicians should be gathered by responsible organizations. This may improve such organizations as the Bureau of Labor Statistics database on this growing industry.
- More research needs to be performed on the working conditions of wind turbine technicians because it is a growing occupation in an energy industry which will likely experience significant growth in the future.
- More research could be performed in regards to the ergonomic risk factor of vibration in the wind turbine working environment. When the survey respondents were asked to rate their exposures to vibration as a risk factor, (where 10 = vibration is often excessive and bothersome, resulting in pain and/or discomfort), 11.11% of respondents rated vibration risk exposure as a 7 out of 10, and 37.04% rating vibration risk exposure as a 6 out of 10. This made it unclear whether vibration is a problematic risk factor for wind turbine technicians and thus further study may be warranted on this topic.
References


American Conference of Governmental Industrial Hygienists (2017). *TLVs and BEIs: Based on the documentation of the threshold limit values for chemical substances and physical agents and biological exposure indices.* Cincinnati, OH: ACGIH.


Appendix A: Great American Insurance Ergonomics 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.

<table>
<thead>
<tr>
<th>Ideal</th>
<th>Warning Level - Monitor</th>
<th>Take Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No repetitive hand or arm motions</td>
<td>1A. Repetitive hand or arm motions with cycle times of 30-60 seconds</td>
<td>1B. Repetitive hand or arm motions with cycle times of less than 30 seconds</td>
</tr>
</tbody>
</table>

#### Posture

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

<table>
<thead>
<tr>
<th>Ideal</th>
<th>Warning Level - Monitor</th>
<th>Take Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head/Neck</td>
<td>Head/Neck</td>
<td>Head/Neck</td>
</tr>
<tr>
<td>4. Head and neck are upright and straight</td>
<td>4B. Bent back less than 10°</td>
<td>4B. Bent back more than 10°</td>
</tr>
<tr>
<td></td>
<td>4C. Bent sideways less than 20°</td>
<td>4C. Bent sideways more than 20°</td>
</tr>
<tr>
<td></td>
<td>4D. Twisting neck less than 20°</td>
<td>4D. Twisting neck more than 20°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ideal</th>
<th>Warning Level - Monitor</th>
<th>Take Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hands</td>
<td>Hands</td>
<td>Hands</td>
</tr>
<tr>
<td>5. Palms are vertical (handshake position)</td>
<td>5A. Hands rotate less than 20°</td>
<td>5A. Hands rotate more than 20°</td>
</tr>
<tr>
<td>Wrist</td>
<td>Wrist</td>
<td>Wrist</td>
</tr>
<tr>
<td>6. Wrists are straight</td>
<td>6A. Wrists are bent between 5 and 30 times per minute and bent less than 20°</td>
<td>6A. Wrists are bent more than 30 times per minute or bent more than 20°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6B. Wrists move sideways between 5 and 30 times per minute and less than 20°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6B. Wrists move sideways more than 30 times per minute or more than 20°</td>
</tr>
</tbody>
</table>

Vibration (Check with tool manufacturer for recommendations or warnings.)

<table>
<thead>
<tr>
<th>Ideal</th>
<th>Warning Level - Monitor</th>
<th>Take Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. No hand or arm vibration</td>
<td>7A. Occasional hand or arm vibration</td>
<td>7B. Constant hand or arm vibration</td>
</tr>
<tr>
<td>8. No whole body vibration</td>
<td>8A. Occasional whole body vibration</td>
<td>8B. Constant whole body vibration</td>
</tr>
</tbody>
</table>
## Reach/Proper Height

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

<table>
<thead>
<tr>
<th>Ideal</th>
<th>Warning Level - Monitor</th>
<th>Take Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>11. Objects lifted by hand weigh less than 1 pound</td>
<td>11A. Objects lifted by hand weigh less than 1 pound and frequent lifting (no more than 20 times an hour)</td>
<td>11B. Objects lifted by hand weigh more than 1 pound or highly repetitive lifting (more than 20 times an hour)</td>
</tr>
<tr>
<td>12. Objects lifted by the back weigh less than 5 pounds</td>
<td>12A. Objects lifted by the back weigh between 5 and 25 pounds or frequent lifting (no more than 20 times/hour)</td>
<td>12B. Objects lifted by the back weigh more than 25 pounds or highly repetitive lifting (more than 20 times/hour)</td>
</tr>
</tbody>
</table>

**Duration**

| 13. No pinch grip used. Fingers and thumb comfortably fit around tool or object | 13A. Moderate pinch grip or pinch grip with less than 2 pounds of force | 13B. Grip is slightly too 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 |
| 17. Gloves do not need to be worn at any time | 17A. Gloves are needed but fit well | 17B. Gloves are needed but fit poorly |

**Choice of Slipperiness**

18. Gloves are worn at all times
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.

<table>
<thead>
<tr>
<th>Ideal</th>
<th>Warning Level - Monitor</th>
<th>Take Action</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Duration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Constant position, tool or object is held less than 6 seconds</td>
<td>Duration 18A. Constant position, tool or object is held 6 to 10 seconds</td>
<td>Duration 18B. Constant position, tool or object is held more than 10 seconds</td>
</tr>
<tr>
<td><strong>Repetition</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. Less than 25% of the task is repetitive</td>
<td>Repetition 19A. 25% to 50% of the task is repetitive</td>
<td>Repetition 19B. More than 50% of the task is repetitive</td>
</tr>
</tbody>
</table>

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.)

<table>
<thead>
<tr>
<th>Ideal</th>
<th>Warning Level - Monitor</th>
<th>Take Action</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Duration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. No contact or impact stress: tools, objects, or workstation do not press against hands or body</td>
<td>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</td>
<td>20B. Constant pressure or impact on hands or body. Hand, knee or other body part used as hammer more than 2 hours/day</td>
</tr>
</tbody>
</table>

Lifting and Materials Handling

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

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

**Comments:**

---

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

**Condition** | **Ideal** | **Warning Level** | **Take Action**
--- | --- | --- | ---

**Repetition**
1. No repetitive hand or arm motions. (Monitor if repetitive cycle every 36-60 seconds; take action if repetitive cycle of less than 30 seconds.)  
   - 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.)  
   - 2A 2B
3. Sitting, back and legs comfortably supported, feet flat on floor/footrest. (Monitor if back partially supported or feet not flat on floor; take action if little support for back and legs, feet not touching floor.)  
   - 3A 3B
4. Head and neck are upright and straight. (Monitor if head and neck are bent forward = 20°; take action if >30° for >1 hour/day.)  
   - 4A 4B
5. Head and neck are bent back. (Monitor if < 90°, take action if <10°.)  
   - 4C 4D
6. Head and neck are bent sideways. (Monitor if < 90°, take action if >20°.)  
   - 5A 5B
7. Wrists are vertical. (Monitor if hands rotate < 20°, take action if hands rotate >20°.)  
   - 6A 6B
8. Wrists move sideways, ulnar/radial. (Monitor if > 20° and 5-30 times/minute; take action if bent >20° or >30 times/minute.)  
   - 7A 7B
9. No hand or arm vibration. (Monitor if occasional; take action if constant.)  
   - 8A 8B
10. No whole body vibration. (Monitor if occasional; take action if constant.)  
    - 9A 9B

**Reach**
11. 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 >36° or constantly out of ideal position >3 hours/day.)  
    - 10A 10B
12. 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.)  
    - 11A 11B
13. 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.)  
    - 12A 12B
14. 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.)  
    - 13A 13B

**Force**
15. Objects lifted by hand weighing less than one pound. (Monitor if objects weighing < 1 lb, are lifted up to 20 times/hour; take action if objects weighing > 1 lb, or lifting occurs >20 times/hour.)  
    - 14A 14B
16. Objects lifted by back weighing less than 5 pounds. (Monitor if objects weighing 5-25 lbs, or lifting occurs up to 20 times/hour; take action if objects weighing >25 lbs, or lifting occurs >20 times/hour.)  
    - 15A 15B
17. No pinch grip used. (Monitor if pinch grip with < 2 lbs of force; take action if pinch grip with >2 lbs of force is used.)  
    - 16A 16B
18. Wide pinch grip used. (Monitor if slightly too wide; take action if extremely wide.)  
    - 17A 17B
19. Power grip used with no force. (Monitor if power grip with < 10 lbs force is used and forearm rotation force is < 5 lbs; take action if power grip with >10 lbs, force is used and forearm rotation force is >5 lbs.)  
    - 18A 18B
20. Entire hand controls trigger. (Monitor if thumb controls; take action if trigger controls.)  
    - 19A 19B
21. Tools or objects have rounded, padded handles. (Monitor if handles are awkward; take action if there are no handles or handles concentrate force.)  
    - 20A 20B
22. Gloves do not need to be worn at any time. (Monitor if gloves are needed but fit well; take action if gloves fit poorly.)  
    - 21A 21B

**Static Loading and Fatigue**
23. Constant position, feet or object is held less than 6 seconds. (Monitor if held between 6-10 seconds; take action if held >10 seconds.)  
    - 22A 22B
24. Less than 25% of the task is repetitive. (Monitor if 25-50% repetitive; take action if >50% repetitive.)  
    - 23A 23B
25. 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.)  
    - 24A 24B
### Summary Worksheet

<table>
<thead>
<tr>
<th>Condition</th>
<th>Ideal</th>
<th>Warning</th>
<th>Take Action</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lifting and Materials Handling</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>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.)</td>
<td>21</td>
<td>21A</td>
<td>21B</td>
</tr>
<tr>
<td>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.)</td>
<td>22</td>
<td>22A</td>
<td>22B</td>
</tr>
<tr>
<td>23. Slight force is required to push or pull materials. (Monitor if moderate force is required; take action if high force is required.)</td>
<td>23</td>
<td>23A</td>
<td>23B</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24. Worker has adequate control over workplace. (Monitor if worker has some control; take action if worker has no control.)</td>
<td>24</td>
<td>24A</td>
<td>24B</td>
</tr>
<tr>
<td>25. Lighting is adequate for the task. (Monitor if slightly too dark or bright; take action if significantly too dark or bright.)</td>
<td>25</td>
<td>25A</td>
<td>25B</td>
</tr>
<tr>
<td>26. Temperature is comfortable. (Monitor if slightly too cold or hot; take action if significantly too cold or hot.)</td>
<td>26</td>
<td>26A</td>
<td>26B</td>
</tr>
<tr>
<td>27. Work area is quiet. (Monitor if slightly too noisy; take action if significantly too noisy.)</td>
<td>27</td>
<td>27A</td>
<td>27B</td>
</tr>
<tr>
<td>28. Flooring provides good traction. (Monitor if floor is slightly slippery; take action if moderately to extremely slippery.)</td>
<td>28</td>
<td>28A</td>
<td>28B</td>
</tr>
<tr>
<td>29. Floor mats are provided. Employee can alternate between sitting and standing. (Monitor if employee is standing up to 100% of shift without floor mats or other stress relief for back and legs; take action if standing more than 50% of shift)</td>
<td>29</td>
<td>29A</td>
<td>29B</td>
</tr>
<tr>
<td>30. Floor mats are provided. Employee can alternate between sitting and standing. (Monitor if employee is standing up to 100% of shift without floor mats or other stress relief for back and legs; take action if standing more than 50% of shift)</td>
<td>30</td>
<td>30A</td>
<td>30B</td>
</tr>
</tbody>
</table>

### Action Plan

**Today's date:**

**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:**

---

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Appendix B: Ergonomic Intake Survey (Symptom Survey)

**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
   - Ankles/Feet

2. Please put a check by the word(s) that best describe your symptoms:
   - Aching/Spasm
   - Numbness/Tingling
   - Swelling
   - Burning
   - Pain
   - Loss of Color
   - Weakness
   - 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
   - 1 hour to 24 hours
   - 24 hours to 1 week
   - 1 week to 1 month
   - 1 month to 6 months
   - 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

13. Please comment on what you think would improve your symptoms: ________________________________
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:
**Appendix C: Anthropometric Data Tables**

**TABLE 1.5**

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

The data are taken primarily from military studies, where several thousand people were studied. The numbers in parenthesis are from industrial studies where 50-100 women and 100-150 men were studied. The data in the footnote are from a study on 50 men and 100 women in industry. Figures 1.13 and 1.14 illustrate the measurements.

The data from men and women are statistically combined to derive the 5th, 50th, and 95th percentile values for a 50/50 mix of these populations.

| Measurement | Males | | | Females | | | Population Percentiles, | | | 50/50 Males/Females | | |
|-------------|-------|---|---|---------|---|---|---------------------|---|---|
| | 50th ± 1 | S.D | 50th ± 1 | S.D | 50th ± 1 | S.D | 5th | 50th | 95th |
| **STANDING** | | | | | | | | | |
| 1. Forward functional reach | | | | | | | | | |
| a. Includes body depth at shoulder | 82.6 | 4.8 | 74.1 | 3.9 | 69.1 | 77.9 | 88.8 |
| | (79.3) | (5.6) | (71.3) | (4.4) | (65.5) | (74.8) | (86.5) |
| b. Acromial process to functional pinch | 63.8 | 4.3 | 62.5 | 3.4 | 57.5 | 65.0 | 74.5 |
| c. Abdominal extension to functional pinch** | (62.1) | (8.9) | (60.4) | (6.7) | (48.5) | (61.1) | (74.5) |
| 2. Abdominal extension depth | 23.1 | 2.0 | 20.9 | 2.1 | 18.1 | 22.0 | 25.8 |
| 3. Waist height | 106.3 | 5.4 | 101.7 | 5.0 | 94.9 | 103.9 | 113.5 |
| | (104.8) | (6.3) | (98.5) | (5.5) | (91.0) | (101.4) | (113.0) |
| 4. Tibial height | 45.6 | 2.8 | 42.0 | 2.4 | 38.8 | 43.6 | 49.2 |
| 5. Knuckle height | 75.5 | 4.1 | 71.0 | 4.0 | 65.7 | 73.2 | 80.9 |
| 6. Elbow height | 110.5 | 4.5 | 102.6 | 4.8 | 96.4 | 106.7 | 116.3 |
| | (114.6) | (6.3) | (107.1) | (6.8) | (98.8) | (110.7) | (123.5) |
| 7. Shoulder height | 143.7 | 6.2 | 132.9 | 5.5 | 124.8 | 137.4 | 151.7 |
| | (146.4) | (7.8) | (135.3) | (6.6) | (126.6) | (140.4) | (156.4) |
| 8. Eye height | 164.4 | 6.1 | 151.4 | 5.6 | 144.2 | 157.7 | 172.3 |
| 9. Stature | 174.5 | 6.6 | 162.1 | 6.0 | 154.4 | 168.0 | 183.0 |
| | (177.5) | (6.7) | (164.5) | (7.2) | (155.1) | (170.4) | (188.7) |
| 10. Functional overhead reach | 209.6 | 8.5 | 199.2 | 8.6 | 188.0 | 204.5 | 220.8 |
| **SEATED** | | | | | | | | | |
| 11. Thigh clearance height | 14.7 | 1.4 | 12.4 | 1.2 | 10.8 | 13.5 | 16.5 |
| 12. Elbow rest height | 24.1 | 3.2 | 23.1 | 3.0 | 18.4 | 23.6 | 28.9 |
| 13. Midshoulder height | 62.4 | 3.2 | 58.0 | 2.7 | 54.5 | 60.0 | 66.5 |
| 14. Eye height | 78.7 | 3.6 | 73.7 | 3.1 | 69.7 | 76.0 | 83.3 |
| 15. Sitting height normal | 86.6 | 3.8 | 81.8 | 4.0 | 76.6 | 84.2 | 91.6 |
| 16. Functional overhead reach | 128.4 | 8.5 | 119.8 | 6.6 | 110.6 | 123.6 | 139.3 |
| 17. Knee height | 54.0 | 2.7 | 51.0 | 2.6 | 47.5 | 52.5 | 57.7 |
| 18. Popliteal height | 44.6 | 2.6 | 41.0 | 1.9 | 38.6 | 42.6 | 47.8 |
| 19. Leg length | 105.1 | 4.8 | 100.7 | 4.3 | 94.7 | 102.8 | 111.4 |
| 20. Upper-leg length | 59.4 | 2.8 | 57.4 | 2.6 | 53.7 | 58.4 | 63.3 |
| 21. Buttocks-to-popliteal length | 49.8 | 2.5 | 48.0 | 3.2 | 43.8 | 49.0 | 53.6 |
TABLE 1.5 (Continued)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Males</th>
<th>Females</th>
<th>Population Percentiles, 50/50 Males/Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50th percentile ± 1</td>
<td>50th percentile ± 1</td>
<td>5th</td>
</tr>
<tr>
<td>22. Elbow-to-fist length</td>
<td>38.5 ± 2.1</td>
<td>34.8 ± 2.3</td>
<td>31.9</td>
</tr>
<tr>
<td>23. Upper-arm length</td>
<td>36.9 ± 1.9</td>
<td>34.1 ± 2.5</td>
<td>31.0</td>
</tr>
<tr>
<td>24. Shoulder breadth</td>
<td>45.4 ± 1.9</td>
<td>39.0 ± 2.1</td>
<td>36.3</td>
</tr>
<tr>
<td>25. Hip breadth</td>
<td>35.6 ± 2.3</td>
<td>38.0 ± 2.6</td>
<td>32.4</td>
</tr>
<tr>
<td><strong>FOOT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26. Foot length</td>
<td>26.8 ± 1.3</td>
<td>24.1 ± 1.1</td>
<td>22.6</td>
</tr>
<tr>
<td>27. Foot breadth</td>
<td>10.0 ± 0.6</td>
<td>8.9 ± 0.5</td>
<td>8.2</td>
</tr>
<tr>
<td><strong>HAND</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28. Hand thickness, metacarpal III</td>
<td>3.3 ± 0.2</td>
<td>2.8 ± 0.2</td>
<td>2.7</td>
</tr>
<tr>
<td>29. Hand length</td>
<td>19.0 ± 1.0</td>
<td>18.4 ± 1.0</td>
<td>17.0</td>
</tr>
<tr>
<td>30. Digit two length</td>
<td>7.5 ± 0.7</td>
<td>6.9 ± 0.8</td>
<td>5.8</td>
</tr>
<tr>
<td>31. Hand breadth</td>
<td>8.7 ± 0.5</td>
<td>7.7 ± 0.5</td>
<td>7.0</td>
</tr>
<tr>
<td>32. Digit one length</td>
<td>12.7 ± 1.1</td>
<td>11.0 ± 1.0</td>
<td>9.7</td>
</tr>
<tr>
<td>33. Breadth of digit one interphalangeal joint</td>
<td>2.3 ± 0.1</td>
<td>1.9 ± 0.1</td>
<td>1.8</td>
</tr>
<tr>
<td>34. Breadth of digit three interphalangeal joint</td>
<td>1.8 ± 0.1</td>
<td>1.5 ± 0.1</td>
<td>1.4</td>
</tr>
<tr>
<td>35. Grip breadth, inside diameter</td>
<td>4.9 ± 0.6</td>
<td>4.3 ± 0.3</td>
<td>3.8</td>
</tr>
<tr>
<td>36. Hand spread, digit one to digit two, first phalangeal joint</td>
<td>12.4 ± 2.4</td>
<td>9.9 ± 1.7</td>
<td>7.5</td>
</tr>
<tr>
<td>37. Hand spread, digit one to digit two, second phalangeal joint</td>
<td>10.5 ± 1.7</td>
<td>8.1 ± 1.7</td>
<td>5.9</td>
</tr>
<tr>
<td><strong>HEAD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38. Head breadth</td>
<td>15.3 ± 0.6</td>
<td>14.5 ± 0.6</td>
<td>13.8</td>
</tr>
<tr>
<td>39. Interpupillary breadth</td>
<td>6.1 ± 0.4</td>
<td>5.8 ± 0.4</td>
<td>5.2</td>
</tr>
<tr>
<td>40. Biocular breadth</td>
<td>9.2 ± 0.5</td>
<td>9.0 ± 0.5</td>
<td>8.3</td>
</tr>
<tr>
<td><strong>OTHER MEASUREMENTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41. Flexion-extension, range of motion of wrist, in radians</td>
<td>2.33 ± 0.33</td>
<td>2.46 ± 0.26</td>
<td>1.92</td>
</tr>
<tr>
<td>42. Ulnar-radial range of motion of wrist, in radians</td>
<td>1.05 ± 0.23</td>
<td>1.17 ± 0.24</td>
<td>0.81</td>
</tr>
<tr>
<td>43. Weight, in kilograms</td>
<td>83.2 ± 15.1</td>
<td>66.4 ± 13.9</td>
<td>47.7</td>
</tr>
</tbody>
</table>

* These values should be adjusted for clothing and posture
** Add the following for bending forward from the hips or waist. Male: waist 25 ± 7; hips 42 ± 8. Female: waist 20 ± 5; hips 36 ± 9
TABLE 1.6
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.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Males 50th percentile ± 1 S.D</th>
<th>Females 50th percentile ± 1 S.D</th>
<th>Population Percentiles, 50/50 Males/Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>STANDING</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Forward functional reach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Includes body depth at</td>
<td>32.5 (31.2)</td>
<td>29.2 (28.1)</td>
<td>27.2 (25.7)</td>
</tr>
<tr>
<td>shoulder</td>
<td>1.9 (2.2)</td>
<td>1.5 (1.7)</td>
<td>30.7 (29.5)</td>
</tr>
<tr>
<td>b. Acromial process to</td>
<td>26.9 (24.4)</td>
<td>24.6 (23.8)</td>
<td>22.6 (19.1)</td>
</tr>
<tr>
<td>functional pinch</td>
<td>1.7 (3.5)</td>
<td>1.3 (2.6)</td>
<td>25.6 (24.1)</td>
</tr>
<tr>
<td>c. Abdominal extension to</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>functional pinch**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Abdominal extension depth</td>
<td>9.1 (41.3)</td>
<td>8.2 (40.0)</td>
<td>7.1 (37.4)</td>
</tr>
<tr>
<td>3. Waist height</td>
<td>41.9 (21.1)</td>
<td>40.0 (38.8)</td>
<td>37.4 (35.8)</td>
</tr>
<tr>
<td>4. Tibial height</td>
<td>17.9 (24.3)</td>
<td>16.5 (3.5)</td>
<td>15.3 (34.8)</td>
</tr>
<tr>
<td>5. Knuckle height</td>
<td>29.7 (45.1)</td>
<td>28.0 (42.2)</td>
<td>25.9 (38.5)</td>
</tr>
<tr>
<td>6. Elbow height</td>
<td>43.5 (45.8)</td>
<td>40.4 (43.6)</td>
<td>38.0 (46.8)</td>
</tr>
<tr>
<td>7. Shoulder height</td>
<td>56.6 (57.6)</td>
<td>51.9 (56.3)</td>
<td>48.4 (49.8)</td>
</tr>
<tr>
<td>8. Eye height</td>
<td>64.7 (69.9)</td>
<td>59.6 (64.8)</td>
<td>56.8 (61.1)</td>
</tr>
<tr>
<td>9. Stature</td>
<td>68.7 (69.9)</td>
<td>63.8 (64.8)</td>
<td>60.8 (61.1)</td>
</tr>
<tr>
<td>10. Functional overhead reach</td>
<td>82.5 (82.5)</td>
<td>78.4 (78.4)</td>
<td>74.0 (74.3)</td>
</tr>
<tr>
<td>SEATED</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Thigh clearance height</td>
<td>5.8 (9.5)</td>
<td>4.9 (9.1)</td>
<td>4.3 (7.4)</td>
</tr>
<tr>
<td>12. Elbow rest height</td>
<td>9.3 (24.5)</td>
<td>9.1 (22.8)</td>
<td>7.3 (21.4)</td>
</tr>
<tr>
<td>13. Midshoulder height</td>
<td>24.5 (31.0)</td>
<td>22.8 (29.0)</td>
<td>23.6 (27.4)</td>
</tr>
<tr>
<td>14. Eye height</td>
<td>31.0 (34.1)</td>
<td>1.6 (1.5)</td>
<td>32.0 (34.1)</td>
</tr>
<tr>
<td>15. Sitting height normal</td>
<td>34.1 (35.2)</td>
<td>32.2 (32.2)</td>
<td>34.6 (37.4)</td>
</tr>
<tr>
<td>16. Functional overhead reach</td>
<td>50.6 (50.6)</td>
<td>47.2 (47.2)</td>
<td>48.7 (54.8)</td>
</tr>
<tr>
<td>17. Knee height</td>
<td>21.3 (21.3)</td>
<td>20.1 (20.1)</td>
<td>18.7 (18.7)</td>
</tr>
<tr>
<td>18. Popliteal height</td>
<td>17.2 (17.2)</td>
<td>16.2 (16.2)</td>
<td>15.1 (15.1)</td>
</tr>
<tr>
<td>19. Leg length</td>
<td>41.4 (41.4)</td>
<td>39.6 (39.6)</td>
<td>37.3 (40.5)</td>
</tr>
<tr>
<td>20. Upper-leg length</td>
<td>23.4 (19.2)</td>
<td>22.6 (18.9)</td>
<td>21.1 (17.2)</td>
</tr>
<tr>
<td>21. Buttocks-to-popliteal length</td>
<td>14.2 (14.2)</td>
<td>12.7 (13.0)</td>
<td>12.6 (11.4)</td>
</tr>
<tr>
<td>22. Elbow-to-fist length</td>
<td>(14.6) (14.6)</td>
<td>13.4 (13.3)</td>
<td>14.5 (11.4)</td>
</tr>
<tr>
<td>23. Upper-arm length</td>
<td>14.5 (14.6)</td>
<td>13.4 (13.3)</td>
<td>13.8 (11.4)</td>
</tr>
<tr>
<td>24. Shoulder breadth</td>
<td>17.9 (14.6)</td>
<td>15.4 (14.6)</td>
<td>14.3 (12.1)</td>
</tr>
<tr>
<td>25. Hip breadth</td>
<td>14.0 (14.6)</td>
<td>15.0 (13.3)</td>
<td>12.8 (12.1)</td>
</tr>
</tbody>
</table>
### TABLE 1.6 (Continued)

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

* These values should be adjusted for clothing and posture.

** Add the following for bending forward from the hips or waist. Male: waist 10 ± 3; hips 16 ± 3. Female: waist 8 ± 2; hips 14 ± 4.