OCCUPATIONAL LOWER EXTREMITY RISK ASSESSMENT MODELING

by:

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ABSTRACT

Introduction Lower extremity (LE) work-related musculoskeletal disorders (WMSDs) are known to occur with cumulative exposure to occupational and personal risks. The objective of this dissertation study was to find if creating a quantifiable risk detection model for the LE was feasible. The primary product of the literature review conducted for this study resulted in focusing the attention of the model development process onto creating the initial model of the LE for assessing knee disorder risk factors.

Literature Review LE occupational disorders affect numerous industries and thousands of people each year by affecting any one of the musculoskeletal systems deemed susceptible by the occupational and personal risk factors involved. Industries known to be affected tend to have labor intensive job descriptions. Some of the numerous industry examples include mining, manufacturing, firefighting, and carpet laying. Types of WMSDs noticed by the literature include bursitis, osteoarthritis, stress fractures, tissue inflammation, and nerve entrapment. In addition to the occupationally related disorders that may develop, occupationally related discomforts were also taken into consideration by this study. Generally, both the disorders and the discomforts can be traced to either a personal or occupational risk factor or both. Personal risk factors noted by the literature include a person's physical fitness and health history (such as past injuries). Meanwhile, occupational risks can be generalized to physical postures, activities, and even joint angles. Prevalence data over a three year interval (2003-2005) has found that LE WMSDs make up on average approximately 7.5% of all the WMSD cases reported to the US Occupational Safety and Health Administration (OSHA). When the literature is refined to the information pertaining to occupational knee disorders, the mean prevalence percentage of the same three year range is about 5%. Mean cost for knee injuries were found to be $18,495 (for the year between 2003 and 2004).

Methodology Developing a risk model for the knee meant using groups of subject matter experts for model development and task hazard analysis. Sample occupational risk data also needed to be gathered for each of a series of tasks so that the model could be validated. These sample data were collected from a sample aircraft assembly plant of a US aerospace manufacturer.

Results Based on the disorder and risk data found in the literature, a knee risk assessment model was developed to utilize observational, questionnaire, and direct measure data collection methods. The final version of this study's knee model has an inventory of 11 risk factors (8 occupational and 3 personal) each with varying degrees of risk exposure thresholds (e.g., high risk, moderate risk, or minimal risk). For the occupational risk assessment portion of the model, the results of task evaluations include both an occupational risk resultant score (risk score) and a task risk level (safe or hazardous). This set of results is also available for a cumulative (whole day) assessment. The personal risk assessment portion only produces a risk resultant score. Validation of the knee risk model reveals statistically ($t(34) = 1.512$, $p = 0.156$), that it is functioning as it should and can decide between hazardous and safe tasks. Additionally, the model is also capable of analyzing tasks as a series of cumulative daily events and providing an occupational and personal risk overview for individuals.

Conclusion While the model proved to be functional to the given sample site and hypothetical situations, further studies are needed outside of the aerospace manufacturing environment to continue testing both the model's validity and applicability to other industrial environments. The iterative adjustments generated for the occupational risk portion of the model (to reduce false positives and negatives) will need additional studies that will further evaluate professional human judgment of knee risk against this model's results. Future investigations must also make subject matter experts aware of the minimal risk levels of this knee risk assessment model so that task observational results are equally comparable. Additional studies are moreover needed to assess the intimate nature between variable interactions; especially multiple model defined minimal risks within a single task.

I’d like to dedicate this dissertation to my parents, my future wife, my family, and my friends who encouraged me to keep praying for strength and wisdom from God so that I could continue moving forward. In particular I would like to thank my father Robert Reid, who along with my mother Margaret Reid juggled multiple jobs through my childhood and college to support the education of my brothers and me. Dad, it is because of the work-related musculoskeletal disorders that I have seen you develop while working labor intensive jobs, that I continue my research in finding prevention methods for these disorders. Your work ethic of hard work and perseverance has finally paid off because it looks as if we now have a doctor in the family. To Dimari, thank you for sticking by my side through all my years of no sleep, isolation, or away from you doing research. I look forward to continuing the rest of our lives together (outside of my PhD).

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CHAPTER ONE：INTRODUCTION

Introduction

Imagine ergonomists working in a manufacturing company. They are informed that their company is about to implement a new product line that will create jobs for the local population as well as new revenue. The company has taken a new approach to the manufacturing and assembly of this new product in that they are very interested in instituting an in-house ergonomics program that will inherently foresee and mitigate ergonomic dilemmas that occur in body which also includes the lower extremity (LE) regions. In the past, predecessors of this product line manufactured and assembled parts using procedures that would include combinations of awkward or sustained postures as well as overexertion, repetition and others over long durations of time. The company's safety and health department have noticed that with these past products there were a high number of incident to worker ratios revealing work-related musculoskeletal disorders (WMSDs) to the LE. To counter these occurrences the company's management would like its ergonomists to assess the probable procedures and change what is necessary to avoid or lower likelihood that these cumulative injuries/illnesses will develop. In order to assess the situation, they will need a way to quantify the risks involved with these procedures and tasks. Utilization of risk assessment models and tools (such as the knee risk assessment model developed in this study) create the quantifiable evidence needed to portray existence and changes in occupational tasks and activities.

Overview

Musculoskeletal disorders (MSDs) in the ergonomic international communities are noted to be labeled under several aliases such as work-related musculoskeletal disorder, cumulative trauma disorders (CTD), repetitive strain injuries (RSI), and occupational overuse syndrome (OOS) (Grieco, G. Molteni, G. De Vito, & Sias, 2006). Grieco et al. (2006) mentions that WMSD would be considered the more optimal term due to it referring its cause to the work environment. They also are using the WMSD label with the presumption of the cause being cumulative (versus traumatic) in nature and the resulting effect being a disorder to the musculoskeletal system. A majority of the manual material handling (MMH) work published in literature about WMSDs, analysis tools, and prevention methods have to do with the upper extremity of the body or the back, with a lack of publications relating to the LE regions (Bruchal, 1995; Lavender, 2006). The purpose of this body of work is to take up the cause mentioned by Bruchal (1995) and Lavender (2006) and 1) submit a more in depth view of the topic of LE WMSDs as well as 2) propose an initial LE Risk Assessment (LERA) model that will provide the initial steps towards the quantification of occupational LE risks. For the sake of time, this study has focused its efforts on developing a LE risk assessment model prototype specifically for the knee.

The LE regions of the body are considered to be the joints and segments of the body from the hip down (hip, knee, ankle, thigh, lower leg, and feet). In this body of work, the sub-systems of the incorporated musculoskeletal system mentioned will include the skeletal, muscular, nervous, and vascular tissues. Vascular tissue although not typically included in WMSD literature is noted to be susceptible to LE cumulative disorders due to occupationally related risks and was therefore included. It is also a necessary sub-system of the LE musculoskeletal system, which would not function when attempting locomotion, postures, or body positions.

Injury/Illness Statistics

National labor statistics is one avenue used to reveal the existence of epidemics or disorders. In 2003, it was revealed that in the United States, the injuries and illnesses reported to have occurred on the job were totaled to be at 4.4 million cases of which 435,180 were considered to be WMSDs. Further analysis reveals that 33,590 WMSD affected the LE with an incident rate of 3.8 cases per 10,000 full-time workers (Bureau of Labor Statistics, 2005a). 2004 revealed a slight decline in the reported incident rates. Of the 4.3 million cases for that year, 402,700 were categorized as WMSDs with 28,770 affecting the LE (incident rate of 3.2 per 10,000) (Bureau of Labor Statistics, 2005b). More recently, 2005 statistical data exposed 4.2 million total reported cases from the Bureau of Labor Statistics. WMSD cases also declined faintly to 375,540. Although total reported injuries and illnesses and WMSDs declined from the previous year, LE WMSDs cases rose to 29,390 with the same 2004 incident rate of 3.2 per 10,000 (Bureau of Labor Statistics, 2006b). This discloses an annual percentage of WMSD cases associated with the LE to be at 7.7%, 7.1% and 7.8% for the years 2003 to 2005, respectively.

Data also unveils that the manufacturing industry is not the only industry susceptible to LE WMSDs. Construction, Trade Transportation & Utilities, Educational & Health

Services, Health Care & Social Assistance, as well as other industries experience these issues also (Bureau of Labor Statistics, 2006b). Lavender (2006) points out that the majority of existing LE WMSD research has been conducted in the athletic and military occupations. He also notes that while the "intensity" of these tasks may not always apply to other occupations, the "cumulative exposure" from them still exists (p. 29-1). These cumulative exposures eventually lead to the development of disorders such as sprain, strain, inflammation, pressure, nerve impairment, reduced blood flow, vasospasms, and even stress fractures (Bureau of Labor Statistics, 2006b; Kroemer, Kroemer, & Kroemer-Elbert, 2001; Laker & Sullivan, 2006).

Human Locomotion, WMSDs, & Discomfort

The human musculoskeletal system is the primary system used to interact with the physical environment during movement. The existence of the LE serves two functions; 1) provide support for the body regions superior to it (head, neck, upper extremities, and torso) as well as 2) provide the ability to perform postures and activities statically or dynamically (Moss, 2009). This system is actually a conglomeration of independent systems that work in cohesion to attain a common goal. The individual systems that comprise the musculoskeletal system are the skeletal, muscular, nervous, and vascular systems. This system conglomeration also includes the ligaments and tendons found in and along joint regions of the body. Initial symptoms of damage to these areas are seen as the aches, pains, and discomforts noticed during or after work or athletic activity. These systems are susceptible to suffering further cumulative damage as they develop into WMSDs. Examples of LE WMSDs include sprains, strains, tissue inflammation, nerve impairment, circulatory impairment, and even stress fractures (Bureau of Labor Statistics, 2006a; Kroemer et al., 2001; Laker & Sullivan, 2006).

Development of WMSDs are not necessarily solely associated to exposure to one type of occupational risk, but is generally attributed to multiple risk variables. These risks can be categorized as personal or occupational in nature. Instances of personal risks may be physical fitness, medical history, or psychosocial influences. The more easily observable occupational risk variables can be viewed for example as repetitive motions (frequency), duration of risk exposure, awkward postures, prolonged static postures, overexertion forces, tissue compression, vibration exposure, and recovery time in between exposures (Crumpton-Young, Killough, Parker, & Brandon, 2000; David, 2005; Hansen, 1993; Kroemer, 1997). Physical postures and activities play large roles in discomfort and WMSD development for the LE. An example may be the case of tissue compression due to leaning on tool and work surfaces (Lavender, 2006). This risk variable can lead to nerve entrapment within the legs as well as knee disorders. Evidence of occupational hazards' influence on WMSDs can be confirmed with the statistical data published annually from the United States' Bureau of Labor Statistics on occupational knee disorders. The grouping of personal and occupational risks can be summed as children of their parent groups. So for LE personal risks, the sub-groups are 1) health and injury history, 2) internal biomechanics (such as tissue tolerances), 3) and possibly psychosocial risks (no study was found or reviewed to directly correlate psychosocial risks with LE WMSDs or discomforts directly). For occupational risks, the sub-groups are 1) joint positions or body postures, 2) movements or activities, and 3) environmental factors.

Research Gaps in Current Risk Detection Methods

Research currently available to ergonomic practitioners and health specialists for WMSDs has primarily focused on occupational risks to the upper extremities (arms and hands), the neck, and the back. Outside of the military and athletic industries, very few studies have been done to associate LE WMSDs to occupational risks (Bruchal, 1995; Lavender, 2006). Generally, studies that do look at risk assessment take into account the whole body with inclusion and brief reference to the LE risks (Corlett, Madeley, & Manenica, 1979; Karhu, Kansi, & Kuorinka, 1977; Kemmlert & Kilbom, 1987; Leonard & Keyserling, 1989; McAtamney & Hignett, 1995). Although many of these tools particularly focus on the postural risks surrounding the knee joint, risk variables contributing to disorders to other regions throughout the LE are neglected. In addition, personal risk factors are not taken into account by these past risk models. This creates a need for LE risk assessment tools (such as this study's proposed knee risk assessment model) for those occupations where LE WMSDs are prevalent.

In short, a problem statement for this dissertation research finds that *except for the knee, risk towards developing LE occupational disorders have not been thoroughly addressed.* Depending on the LE region, numerous industries are concerned with LE disorders (such as construction, fishing, manufacturing, or mining). To tackle this problem, this dissertation takes aim at where existing tools have left practitioners stranded (the knee joint). The dissertation hypothesis of this research *looks to see if like models of the upper extremity and lower back, a LE method can be developed for assessing risks that lead to WMSDs.*

Developing a Lower Extremity Risk Model

The initial objective of this research was to build an epidemiological case that reviewed not just costs, incidents, and injuries, but also associated the risks to the effects. Once this taxonomy had been gathered, the results could be formulated into task development guidelines that would eventually lead to risk model conception. The primary objective of this dissertation research itself was to *address the dissertation problem statement and hypothesis by creating a model that is able to quantify occupational risks as well as personal risk variables into a set of equations that can approximate the total risk to a worker's LE regions during a job or task.* This objective would be applicable to the knee for the case of this study. In addition to this methodology, data collection methods, model intricacies, and model benefits were also incorporated into the development process and culminated in the knee risk assessment model result.

Data Collection Methods

The methods used for the capturing of information have to be acknowledged in the development or selection of models and tools. These include the use of self-reporting, observational, and direct measurement methods (David, 2005; Li & Buckle, 1999; van der Beek, A. J. & Frings-Dresen, 1998). David (2005) adds that accuracy increases along with subject invasiveness as one progresses from using self-reports to observational methods, to direct measurements. Self-reports such as questionnaires (surveys), checklists, diaries, or interviews can be used to capture both physical (work load and pain/discomfort) and psychosocial (worker stress) aspects of a task (David, 2005; Li & Buckle, 1999; Pinzke, 1997).

The more common method employed by researchers based on the tools that have developed, is the observational method, which can be divided into paper or software applications (David, 2005; Li & Buckle, 1999). Paper methods can be quick print outs that are capable of being filled out in the actual environment at the time of the task, whereas software applications require the use of a computer to be at the site of the observation. Some computer based observational techniques include the capability of uploading photographs and video as well as generating 2D and 3D human mannequins to increase the contextual nature of the ergonomic problems. Sometimes these two sub-methods intermingle with each other, meaning that paper based methods have been programmed into software with the capability of being printed out for site assessments whose information will later be integrated back into the software for analysis.

Time-sampling (snapshots) and real-time video capture are other criteria that are of concern when using observational methods (Fransson-Hall et al., 1995; Genaidy, Al-Shedi, & Karwowski, 1994; Pinzke, 1997). Time-sampling observation captures a static image of a worker's body posture whether directly through the methods of the model itself (such as video-analysis software) or indirectly through the analysis of photographs or frozen frames of video recordings. This method only provides a glimpse at the context of the risk involved. If more snapshots are taken of a task being performed then a more holistic view of the problem can become apparent, thus increasing the accuracy of a diagnosis (Fransson-Hall et al., 1995; Pinzke, 1997). It should be noted that time-sampling frequency throughout a task was recommended to be at least one snapshot every 30 seconds for analyses that don't incorporate video recording and for those that do, every 3 seconds (Pinzke, 1997). Contrarily, real-time video capture allows the complete flow of activities throughout a task to be investigated at anytime due to it being a recording (Pinzke, 1997). Fransson-Hall (1995) continues by saying that real-time video capture also offers the possibility to acquire durations and frequencies of task activities.

Direct measurement is the third method used for information capture (David, 2005; Li & Buckle, 1999). Li and Buckle (1999) comment that the direct measurement method has two sub-categories (postural assessment and musculoskeletal strain/fatigue). Postural assessment using direct methods denotes the usage of hand held devices (such as goniometers or anthropometers) or electronic devices (such as accelerometers or optical scanners) for body posture measurement. Musculoskeletal strain and fatigue can also be measured and recorded by researchers using direct measurement methods. Examples of this method include the use of electromyography to approximate muscle tension (David, 2005) and spinal taps with pressure transducers to estimate spinal compression (Li & Buckle, 1999).

The methodology developed for using this study’s knee risk assessment model utilizes all three of the aforementioned data collection methods. Questionnaires are used for collecting personal risk information, video observation is used for risk exposure durations and frequencies, and direct measure for collection variables such as object weight or possibly walking distance (pedometers).

Risk Model Intricacies

A model is described as a system that simulates a real world activity or process using variables and constraints in order to better understand the system that it duplicates (Kroemer et al., 2001). Practical and analytical industrial analysis models and tools allow 1) untrained personnel to use it easily and reliably with little training (Corlett et al., 1979; Karhu et al., 1977), 2) provide clear understandable results, 3) if possible, provide feasible actions or solutions to correcting the problem (Karhu et al., 1977), and 4) be capable of digital integration (if not already) into computer systems for later analysis and retrieval (Corlett et al., 1979).

When considering the trade off between the generality of application and the sensitivity/accuracy of tool and model results, suggestions are offered that can help clarify one's decision making process (Fransson-Hall et al., 1995; Hignett & McAtamney, 2006). Hignett and McAtamney (2006) in particular propose significant considerations for choosing between tools for the industrial practitioner as seen in Table 1-1 (p. 42-1-42-2).

Table 1-1 Categories and questions to consider when choosing between risk tools and models (Hignett & McAtamney, 2006)

Category of consideration	Question for consideration
Task	Which area of the body is being assessed, for example whole body or upper limbs?
	Does the activity include static and dynamic postures?
Sensitivity & Generality	How detailed will the assessment be?
	Will the same postural analysis tool be used for a range of tasks in several industrial settings?

Validity and reliability testing are the final confirmations of an effective model or tool. Validity testing is typically done by comparing the results of the test tool against that of either a publicly accepted tool or epidemiological evidence (gold standard testing). Reliability on the other hand, means that the same results will continuously be output regardless of whether the testing is done by the same person (intra-reliability) or by different investigators (inter-reliability). Validity and reliability tests are classically completed over several years by multiple studies in multiple environmental settings (Pinzke, 1997). For the case of this LERA knee study, since previous validated tools were not available, the validation was completed by comparing the results to epidemiology, professional judgment of subject matter experts, and work location incident rates. Reliability testing was not conducted for this study and should be considered for future research that tests this model.

Benefits of a Risk Model

Ergonomics and biomechanics research has been productive in replicating or simulating the performance of the lower extremity for different tasks such as analyzing the gaits of people who have had osteoarthritis in the hip (Cichy & Wilk, 2006). Research has also been able to produce improved assistance equipment or personal protective equipment such as the Berkeley Lower Extremity Exoskeleton (BLEEX) that will allow an increase in the LE's strength and fatigue capacities (Kazerooni, Steger, & Huang, 2006). Current risk models tend to review the body as the upper extremity (Li & Buckle, 1998; McAtamney & Corlett, 1993), lower back (Snook & Ciriello, 1991; Waters, Putz-Anderson, Garg, & Fine, 1993), or whole body (Corlett et al., 1979; Karhu et al., 1977; McAtamney & Hignett, 1995; McAtamney & Hignett, 1995; Priel, 1974). A risk analysis

tool for the LE in occupational settings has not been found to be published as of yet, therefore, proposal of a knee risk assessment tool would prove useful.
Furthermore, models and tools highlighting particular regions or segments of the body allow intricacies and nuances to be exposed in greater detail (Gil & Tunes, 1989). The significance of this knee assessment model is in the concept of considering risk factors beyond, standing, walking, kneeling, or squatting. With the addition of other risk factors found in epidemiology, the knee assessment model resulting from this study creates a methodology by which other LE body regions can now be acknowledged.

The benefits of such a model can aid in the development of higher quality tools, workplaces, and task procedures (Hansen, 1993). In addition, this model can also be used to aid epidemiological research's quest to find associations between jobs and WMSDs (Kemmlert & Kilbom, 1987). The investigational and development processes contrived from this study, also serve as a platform from which further retrospective and prospective research can progressively aid in the reduction or elimination of LE occupational hazards.

CHAPTER TWO : LITERATURE REVIEW

Lower Extremity Musculoskeletal System Anatomy & Physiology

It is important to remember that the body is a collection of systems linked through joints and segments. The LE musculoskeletal system involves those systems that contribute to both the structural support of the body and the ambulant behavior normal in human beings (Moss, 2009). These systems are the muscular, skeletal, nervous, vascular, and endocrine systems (Kroemer et al., 2001). Occupational related risks can affect these systems of the body. In particular, Kroemer et al. (2001) mentions that these risks can damage or impair normal function of the muscular, vascular, nervous, and even skeletal systems.

Musculoskeletal physiology within the lower extremity is particularly unique in that its purpose is for whole body static posture and dynamic transportation. In reference to the lower extremity, Hamill and Knutzen (2003) point out that "It is important to evaluate movement and actions in both limbs, the pelvis, and the trunk rather than focus on a single joint to understand lower extremity function for the purpose of rehabilitation, sport performance, or exercise prescription" (p. 172). Knowing this helps us better understand why it is important to be aware of the tasks and occupations of today's work places and how our musculoskeletal system interacts with them.

Skeletal System

Our endoskeleton consists of rigid bones that form the structure of the musculoskeletal system. Other than structural support, the skeletal system functions as a system of protection, blood cell formation, storage and levers. The structural design of a bone is a cancellous (spongy bone) core surrounded by a cortical (compact bone) casing (Hamill & Knutzen, 2003). It is also noted that cancellous bone although efficient at stress absorption, is structurally weaker than cortical bone. Hamill and Knutzen also say that the lower extremity embodies long, short, flat, irregular and sesamoid (embedded in tendon or joint) bone types.

The lower extremity skeletal system is comprised of the segments of the pelvic girdle, thigh, lower leg, foot and the joints that connect the regions with each other. A majority of the joints of the lower extremity are considered as synovial joints as they have cavities containing synovial fluid. The largest articulation points between the segments are the hip, knee, and ankle. Other articulation points comprise that between the tibia and fibula, the tarsus (tarsals), the tarso-metatarsal regions, the metatarsals themselves, the metatarso-phalangeal segments, and the phalanges (Gray, 1977). The bones and joints are held in place through systems of cartilage, tendons, and ligaments (Clancy & McVicar, 1995).

Hip

The pelvic girdle of the human body is a crucial linking point between the upper extremity's torso and the lower extremity's legs. Hamill and Knutzen (2003), mention that this important link is the fulcrum between the actions of the two extremities. As one leg or extremity is placed into a posture, it is counter-balanced by anther region through the structure of the pelvic girdle. The hip segment of the body is structurally supported by the pelvic girdle which in itself consists of the three bones ilium, ischium, and os pubis (Figure 2.1) (Hamill & Knutzen, 2003). These bones are known to fuse during puberty so as in adult age they become a single unit known as an ossa innominata. In the human body, Gray (1977) notes that the pelvis includes a right and left side innominata, as well as the sacrum and coccyx. The joint formed by the mating of the thigh to the pelvis through the femur head to the hip's acetabulum socket is known as a ball and socket joint. This type of joint permits three degrees of freedom allowing the movements of flexion, extension, abduction, adduction, medial rotation, lateral rotation, and circumduction (Hamill & Knutzen, 2003).

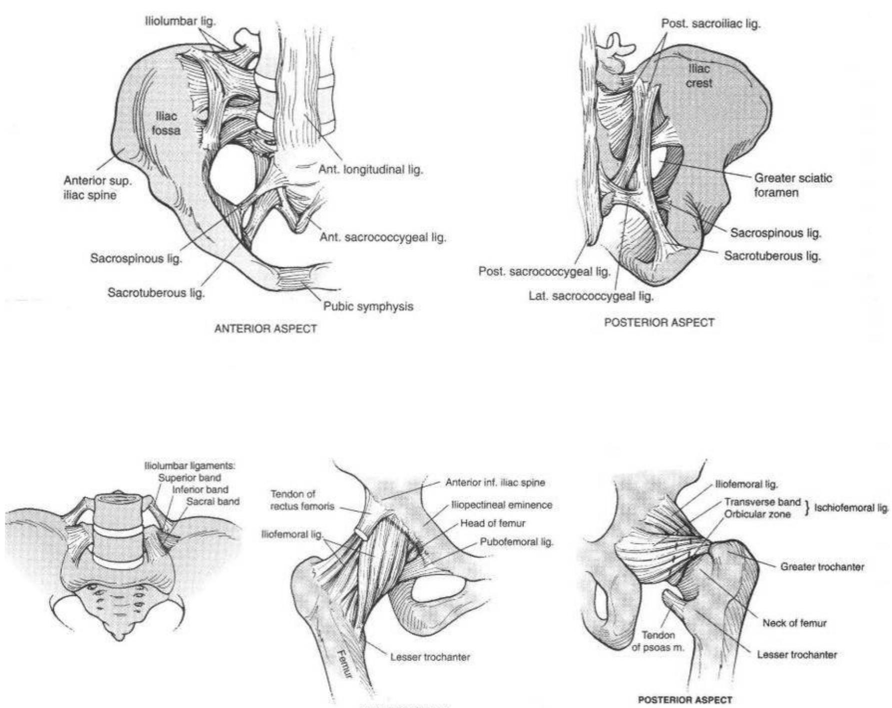

Figure 2.1 Bones and tendons of the pelvic girdle and hip joint. Reprinted with permission from Hamill, J. & Knutzen, K.M., Biomechanical Basis of Human Movement, Lippincott Williams & Wilkins, 2003.

Knee

The knee (Figure 2.2) is the joint of the human body that links the inferior portion of the femur to the superior portion of the shin bone (tibia). While the thigh consists of only the femur bone, the lower leg has two bones; the tibia and fibula. Located at the center of the anterior portion of the knee, is the third bone known as the patella (knee cap). These three bones together form a general synovial hinge joint, but, in actuality it is a compilation of two ellipsoidal joints at each femoral condyle (medial and lateral) and one gliding joint between the femur and the patella (Clancy & McVicar, 1995; Gray, 1977). Yamato and Brada (1996), mention that the knee has multiple ligaments for stabilization. In addition, they also say that there is a lateral and medial meniscus on both sides of the knee for extra structural support. The knee joint will permit two degrees of freedom allowing the movements of flexion, extension, slight medial rotation, and slight lateral rotation (Hamill & Knutzen, 2003).

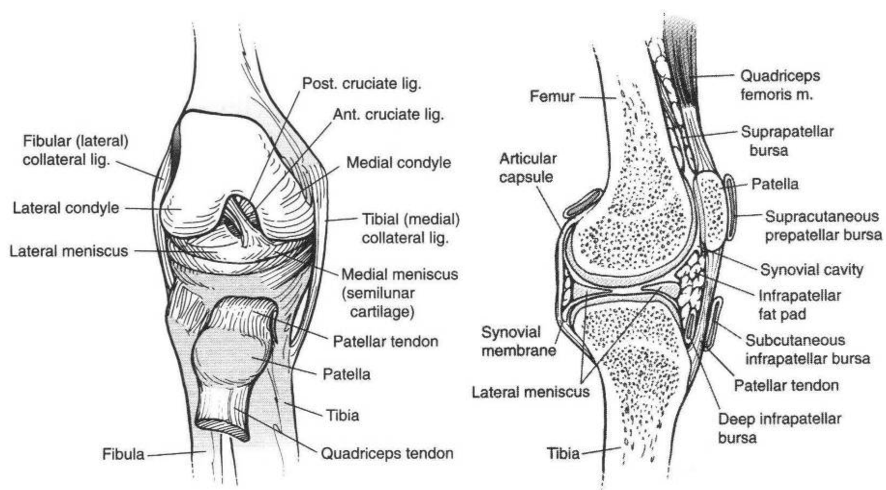

Figure 2.2 Bones and tendons of the knee joint. Reprinted with permission from Hamill, J. & Knutzen, K.M., Biomechanical Basis of Human Movement, Lippincott Williams & Wilkins, 2003.

Ankle

The ankle joint (Figure 2.3) is a hinge joint uniting the lower leg to the foot. The inferior portions of the bones of the lower legs form the medial and lateral sides of the ankle (inner malleolus from the tibia and the external malleolus from the fibula) (Gray, 1977). The inner and external malleolus attach to the main ankle-foot tarsal known as the talus. The other tarsals of the foot include the calcaneus (heel bone), three cuneiform bones (internal, middle, and external), cuboid, and navicular bone to total to seven tarsals. The degrees of freedom offered by the ankle are one, which includes plantar flexion and dorsiflexion (Hamill & Knutzen, 2003).

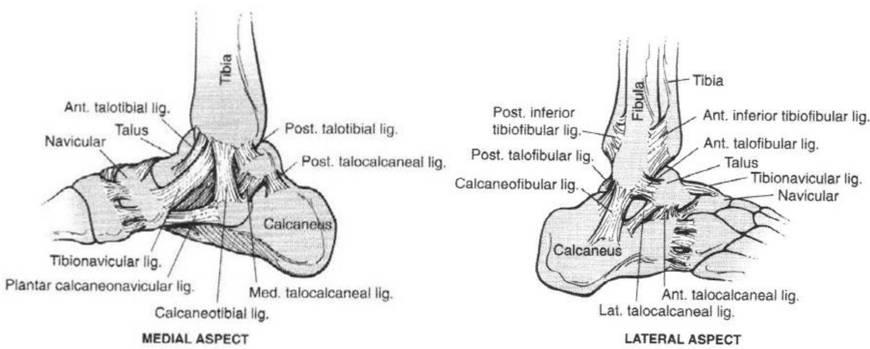

Figure 2.3 Bones and tendons of the ankle joint. Reprinted with permission from Hamill, J. & Knutzen, K.M., Biomechanical Basis of Human Movement, Lippincott Williams & Wilkins, 2003.

Additional Joints of the Lower Extremity

Between the hip and the knee, the bones of the tibia and fibula are connected in three points. These articulation points are noticed at the superior, middle, and inferior segments of the bones. The extreme points are gliding joints connected by ligaments whereas the middle articulation points are considered as a barrier between the posterior and anterior muscle groups (Gray, 1977).

Located in the foot are supplementary articulation points other than the ankle. These include the connections between the bones of the tarsals, such as the calcaneus with the talus, the calcaneus with the cuboid, the calcaneus with the navicular, the talus with the navicular, the navicular with the cuneiform bones, the navicular with the cuboid, and the cuneiform bones with each other. Their articulate structures differ from that of a gliding joint to that of non-movement (Gray, 1977). The calcaneus bone structure supports 50% of the body's total weight (Konz, 1999). The tarsals as a whole offer 3 degrees of freedom, which allows the movements of inversion and eversion (Hamill & Knutzen, 2003).

The tarso-metatarsal joints are considered gliding joints. They consist of the four tarsal bones (internal cuneiform, middle cuneiform, external cuneiform and cuboid) mated to the five metatarsals of the toes. The first three metatarsals starting with the big toe coordinate with the three cuneiforms accordingly (first metatarsal to internal cuneiform and so on). The fourth metatarsal bone connects to both the external cuneiform and the cuboid bones. The fifth metatarsal bone is connected solely to the cuboid (Gray, 1977). It is through the metatarsal bones that the remaining half of the body weight is can be dispersed. The first and second metatarsals absorb 25% of the outstanding 50% while the other half is of the weight is through the third through fifth metatarsals (Konz, 1999).

Konz (1999) reveals that the joints and bones of the rear and mid-foot combine to form the two arches of the feet. The first arch is the medial arch that is composed of the calcaneus, talus, navicular, cuniform bones and the first three metatarsals. The second arch or lateral arch uses the remaining metatarsals (fourth and fifth), the calcaneus, talus, and cuboid.

Dividing each metatarsal from each other is a series of ligaments (except between the first and second metatarsal). These ligaments attach on the dorsal, plantar, and interosseous sides of the metatarsals. Connected to the distal portions of each metatarsal is a phalange of the metatarso-phalangeal joint. These ellipsoidal joints are connected through a network of plantar, lateral, and posterior ligaments (Gray, 1977). The metatarsophalangeal joints allow 2 degrees of freedom. Their movements incorporate flexion, extension, abduction, adduction, and circumduction (Hamill & Knutzen, 2003).

The last set of joints of the lower extremity includes the phalanges themselves. Each toe contains three phalange bones except for the big toe which only has two. These phalange joints are considered hinge joints with one degree of freedom and movements of flexion and extension (Gray, 1977; Hamill & Knutzen, 2003).

Muscular System

If the skeletal system is the rigid structural framework of the LE's musculoskeletal system, then the muscular system is the engine (or system of engines) that moves that framework during locomotion and stabilize it when holding static postures. The skeletal muscles (Figures 2.4, 2.5, and 2.6) of the lower extremity portions of the human body are used primarily for leverage and locomotion. They are also used for stability of the skeletal segment and joint structures both during a dynamic activity and during a static posture (Clancy & McVicar, 1995; Hamill & Knutzen, 2003; Yamamoto & Brada, 1996). The muscles of the human lower extremity are grouped by the segment they correspond to (pelvic girdle, thigh, lower leg, and foot) (Gray, 1977). These muscles can be attached to the skeleton through either strong but flexible tissue known as tendons, or aponeurosis (fibrous sheath), or directly to the bone (Hamill & Knutzen, 2003).

Muscle Groups and Their Locations

Per Gray's (1977) anatomy research, the following Table 2-1 is a compilation of the muscle groups and the segment regions that they pertain to:

Table 2-1 Lower Extremity Muscle Groups adapted from Gray (1977)

Lower Extremity Segment Region	Anatomical Relative Position	Muscle Tissue Layer	Muscle Group
Pelvic Girdle (Iliac)	NA	NA	Psoas Magnus; Psoas Parvus; Iliacus;
Thigh	Anterior Femoral	NA	Tensor Fasciae Femoris; Sartorius; Quadriceps Extensor (Rectus femoris; Vastus Externus; Vastus Internus; Crureus;); Subcrureus;
	Internal Femoral	NA	Gracilis; Pectineus; Adductor Longus; Adductor Brevis; Adductor Magnus;
	Gluteal	NA	Gluteus Maximus; Gluteus Medius; Gluteus Minimus; Pyriformis; Obturator Internus; Gemellus Superior; Gemellus Inferior; Quadratus Femoris; Obturator Externus;
	Posterior Femoral	NA	Biceps femoris; Semitendinosus; Semimembranosus;
Lower Leg	Anterior Tibio-fibular	NA	Tibialis Anticus; Extensor Proprius Hallucis; Extensor Longus Digitorum; Peroneus Tertius;
	Posterior Tibio-fibular	Superficial	Gastrocnemius; Soleus; Plantaris;
		Deep	Popliteus; Flexor Longus Hallucis; Flecrexor Longus Digitorum; Tibialis Posticus;
	Fibular	NA	Peroneus Longus; Peroneus Brevis;

Lower Extremity Segment Region	Anatomical Relative Position	Muscle Tissue Layer	Muscle Group
Foot	Dorsal	NA	Extensor Brevis Digitorum;
	Plantar	First	Abductor Hallucis; Flexor Brevis Digitorum; Abductor Minimi Digiti;
	Internal Femoral	Second	Flexor Accessorius; Lumbricales;
	Gluteal	Third	Flexor Brevis Hallucis; Adductor Obliquus Hallucis; Flexor Brevis Minimi Digiti; Adductor Transversus Hallucis;
	Posterior Femoral	Fourth	The Interossei;

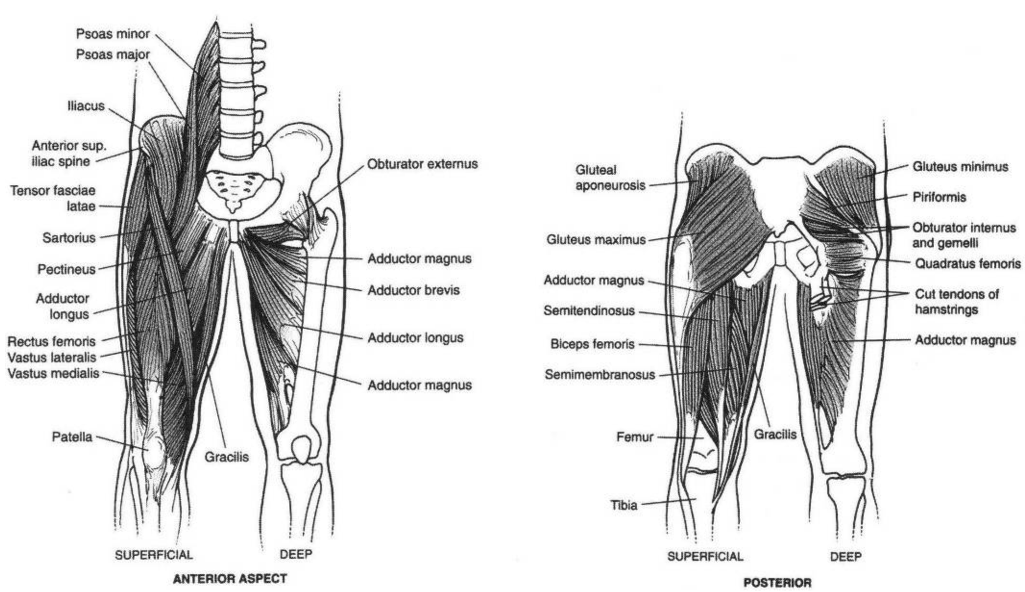

Figure 2.4 Muscles and tendons of the pelvic and thigh regions. Reprinted with permission from Hamill, J. & Knutzen, K.M., Biomechanical Basis of Human Movement, Lippincott Williams & Wilkins, 2003.

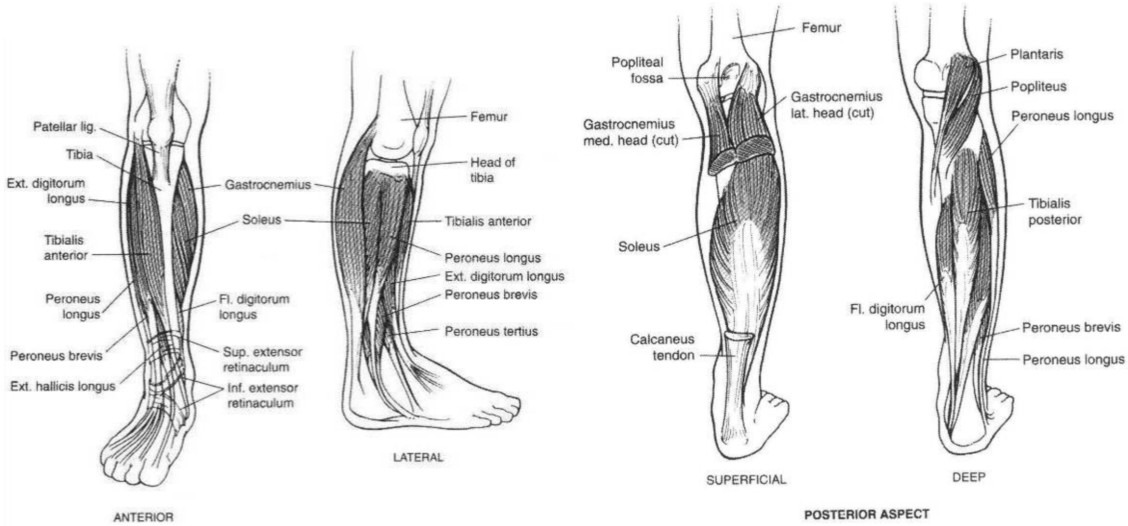

Figure 2.5 Muscles and tendons of the lower leg region. Reprinted with permission from Hamill, J. & Knutzen, K.M., Biomechanical Basis of Human Movement, Lippincott Williams & Wilkins, 2003.

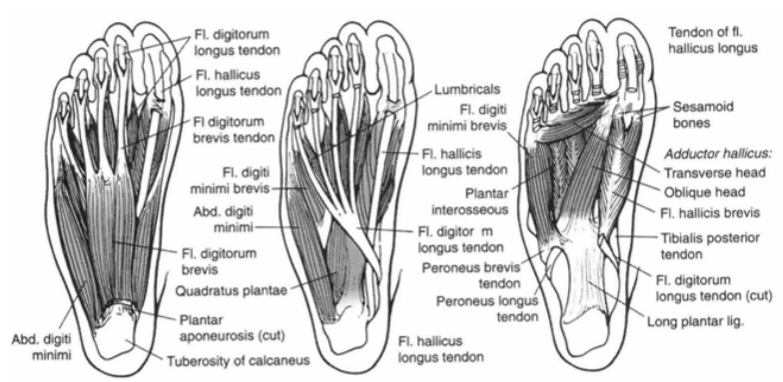

Figure 2.6 Muscles and tendons of the foot. Reprinted with permission from Hamill, J. & Knutzen, K.M., Biomechanical Basis of Human Movement, Lippincott Williams & Wilkins, 2003.

Muscle Fiber Arrangement

Strength, speed, and length change are three products that are determined by the fiber arrangement of the muscles (Hamill & Knutzen, 2003). The method of delivery for the end result differs depending on the fiber arrangement of the muscle which in turn could be considered in how muscle usage is determined.

Fusiform fiber arrangement is the shaping of the muscle fibers length with that of direction of force during muscle contraction. An analogy of this fiber arrangement could be that of a rope. When taught and in use, the forces that travel through the rope flow in the direction of its length. They are the longest muscle fibers in the body with the shortest tendon attachments. This offers a greater range of length change during muscle contraction (30-50% from resting length) as well as an advantage in speed (Hamill & Knutzen, 2003).

Penniform fiber arrangements have a tendon that runs along its length down the middle of the muscle group. From this tendon branches of muscle fiber are situated diagonally from end to end. The structure is similar to that of a bird's feather. These arrangements can be unipennate (along one side of the tendon), bipennate (along both sides of the tendon), or multipennate (combination of the previous two). The benefit of these muscle fiber arrangements is that they are capable of a higher amount of force when compared to Fusiform. This is due to a greater cross-sectional length of muscle fibers (Hamill & Knutzen, 2003).

Muscle Type

Aside from muscle fiber arrangement for mechanical advantages, one should also consider muscle fiber type which also has metabolic variations. There are two divisions of muscle type (I and II) and within type II there are two sub-divisions (a and b). Each division produces energy with different methods and therefore has different energy consumption rates. Muscle groups usually contain combinations of both Type I and Type

II, with the chosen usage depending on subject muscle training (Hamill & Knutzen, 2003).

Type I fibers or ‘slow’ twitch fibers are high in blood and oxygen supply. They use aerobic metabolism to produce the necessary energy of Andenosine Triphosphate (ATP) for muscle movements (Clancy & McVicar, 1995). The benefit of this muscle type is that it is slow to fatigue and is useful for low-intensity tasks with long durations (Hamill & Knutzen, 2003).

Type II muscle fibers are known as ‘fast’ twitch muscle fibers. They are capable of generating highly intense bursts of speed and force which as a repercussion consumes energy more rapidly. The reason behind the expedited energy consumption is due to the anaerobic metabolic process. Minute amounts of myoglobin are available to Type II muscle fibers and therefore energy is mainly supplied via mitochondria and sarcoplasmic reticulum (Clancy & McVicar, 1995). Hamill (2003), mentions that Type IIa (oxidative-glycolytic) fibers are considered as a hybrid of the Type I and Type II divisions. They are capable of low intensity-long duration or high intensity-short duration. The Type IIb (glycolytic) fibers are strictly for high intensity-short duration tasks. Lactic acid is another resultant of the metabolic processing and is also an impedance on effective muscle function. The more energy required from the muscle groups for a task, the more lactic acid is produced within them. Thus, muscle fiber type used will indirectly affect the onset rate of muscle fatigue. An individual’s genetic predisposition determines the quantity of each Type’s division and sub-division.

Muscle Group Contractions

Skeletal muscle groups can contract in a variety of manners. Depending on the task at hand a person can contract the skeletal muscles of the lower extremity to fit his or her need. Tension is the biomechanical force applied along muscles during a contraction (Hamill & Knutzen, 2003). Hamill and Knutzen (2003) mention that again depending on the task, this resulting contraction can either shorten (concentric contraction) or lengthen (eccentric contraction) the activated muscle.

Clancy and McVicar (1995) reveal that stimulus signals sent by the brain through the nervous system to a muscle can respond in contraction by a twitch, treppe, tetany, isotonic, or isometric fashion. *Twitch* contractions are due to a single stimulus, thus producing a single contraction resembling a spasm. *Treppe* contractions are a series of contractions that increase in stimulus intensity. The muscles are allowed to relax between each stimulus, thus creating an oscillation of contract and relax intervals. Muscle contraction in *tetany* mode (tetanic contraction), is similar to treppe except that the muscles are not allowed to entirely return to their rest state. Instead, the muscle is in a near continuous contraction due to the rapid succession of stimulus. The fourth type of muscle contraction is *isotonic*. This is when muscle tension remains constant while muscle length changes. This contraction is useful for motions that involve a sustaining force from the muscles as their lengths begin to change during a motion. The last type of contraction is *isometric.* If the joint being utilized is in a static posture but the muscles are being used in a sustained force and are not changing in length, then the muscle can be described as contracting in an isometric way (Clancy & McVicar, 1995).

Nervous System

The nervous system is the communications highway for the musculoskeletal system. The body's nervous system is composed of two major halves. The first is the peripheral nervous system (PNS), whose function is to serve the other half called the central nervous system (CNS) (Marklin, 1999). The PNS acts as the branches and leaves of a tree, reaching outwards from the CNS (tree trunk) to the distal portions of the appendages. The PNS is divided into the somatic (SNS) and autonomic (ANS) nervous systems. Muscle units controlled in a voluntary manner are part of the SNS whereas muscle units with involuntary control are part of the ANS. This sub-division of the PNS has two sub-systems of its own; the sympathetic (SNS) and parasympathetic (PSNS) nervous systems. The CNS consists of the brain and spinal cord (Gray, 1977; Hamill & Knutzen, 2003).

Both the SNS and ANS are capable of communicating signal information afferently and efferently. Since we use our musculoskeletal system for voluntary actions, afferent and efferent descriptions will relate to the SNS. The primary tasks of the PNS' SNS is 1) to relay information from the sensory receptors to the CNS (Afferent system) and 2) to return motor response impulses from the CNS to the motor units (effectors) in order to maintain motor control of the skeletal muscles (Efferent system) (Clancy & McVicar, 1995; Hamill & Knutzen, 2003).

This is accomplished through the pathways established by the CNS's spinal cord within the spinal column. Hamill and Knutzen (2003) point out that each spinal nerve pair of the spinal cord coordinates with different portions of the skeletal muscles. Each nerve pair has an entrance and exit pathway (dorsal root and ventral root, respectively). The dorsal root is connected to the spinal cord on the posterior side of the body bringing sensory signals into the spinal nerve. The nerves that leave on this side of the spinal cord are labeled as sensory neurons. On the anterior side of the spinal nerve is the pathway for the ventral root. This pathway is used to send muscular contraction signals. Similarly, the nerve paths that leave this side of the spinal cord are called motor neurons.

Proprioreception

We as human beings perceive our interactions with the world around us through a network of nerves and receptors within our nervous system. Pressure sensitive or distortion sensitive receptors are known as mechanoreceptors whereas the brain's awareness of the musculoskeletal system's posture and their locations to the body and each other is through proprioreceptors (Clancy & McVicar, 1995). Proprioreceptors, also known as proprioceptors, convey not only musculoskeletal posture, but also muscle length or tension to the central nervous system (Hamill & Knutzen, 2003). This sensory receptor system is made up of vestibular receptors, joint receptors, tendon receptors, and muscle spindles. Clancy and McVicar (1995), mention that this system is not only capable of monitoring static posture, but dynamic as well. The ability to be aware of one's continuously stopping and changing postures during an activity is crucial for any task we may be involved in.

Nervous Pathways of the Lower Extremity

The PNS separates from the CNS once the nerve pathways leave the spinal column's spinal cord. Our lower extremity region consists of five pairs of nerves that leave the spinal cord at the lumbar region, five pairs that leave the sacral region and one pair from the coccygeal (Figure 2.7) (Hamill & Knutzen, 2003). From a superior to inferior approach, the nerves that leave the sacral region that discontinue within the buttocks are the superior gluteal nerve and the inferior gluteal nerve. From the lumber spinal region, leave the obturator and femoral nerves, with the former ending in the pelvis and the latter continuing into the medial anterior portion of the thigh.

The posterior portion of the leg is reserved for the sciatic nerve. Gray (1977) mentions that the sciatic nerve is the largest nervous pathway in the human body by girth. This nerve will continue its path towards the posterior inferior portion of the femur until it divides into two branches (Yamamoto & Brada, 1996). From these two branches sprouts additional channels of nervous pathway. Hamill and Knutzen (2003) illustrate that the two posterior branches are the common peroneal nerve along the lateral-posterior portion of the lower leg and the tibial nervous pathway within the central region of it.

The common peroneal nerve forks in two again as it curves along the lateral portions of the lower leg from the posterior to the anterior side near the middle of the tibia and fibula. The superficial peroneal nerve maintains its course along the lateral side of the leg while the deep peroneal nerve branches into the medial region of the lower legs. Both flow downwards into the dorsal portions of the feet to become their digital branches. The tibial nerve meanwhile, continues its course into the plantar regions of the foot, curving around the medial malleolus and the heel to part into the medial and lateral plantar nerves. All of these main branches mentioned continue to divide and branch off into the muscular and cutaneous sections of the LE.

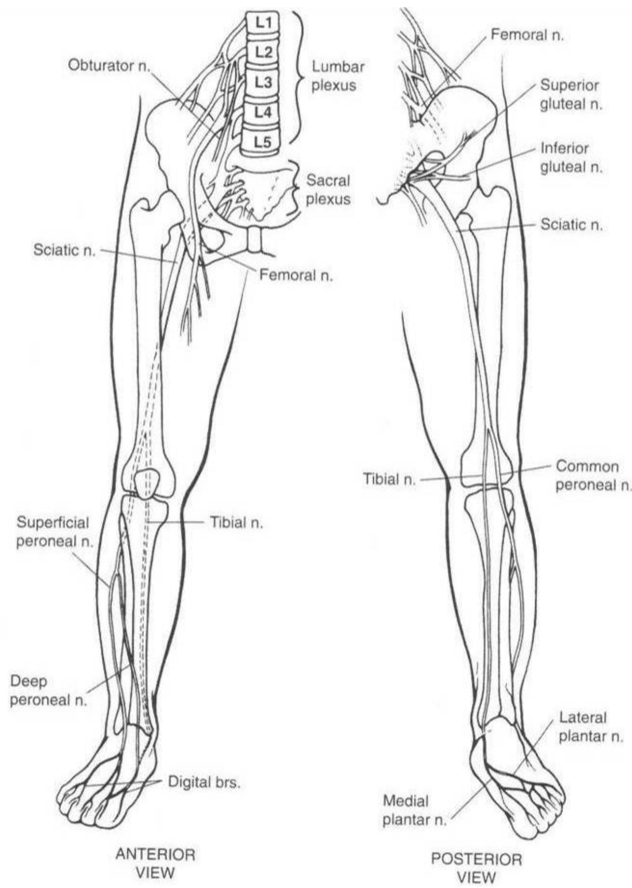

Figure 2.7 Nerves of the lower extremity regions. Reprinted with permission from Hamill, J. & Knutzen, K.M., Biomechanical Basis of Human Movement, Lippincott Williams & Wilkins, 2003.

Vascular System

Gray (1977) created a detailed surgical taxonomy of the vascular system of the human body. In his research, he wrote that the vascular or circulatory system encompasses the heart, the fluidic medium blood, and the blood vessels that transport and deliver the blood. Because human beings only have one heart located in the chest, only the latter two sub-systems (arterial and venous) of the vascular system pertain to the LE. Blood vessels themselves can be considered as a set of vascular sub-systems known as the arterial and venous systems. The function of the arteries is to deliver the blood's oxygen and nutrients to the body's tissue after it has been pumped out of the heart. The responsibility of the veins is opposite, to return the blood back to the heart as well as collect the waste and metabolic bi-products from tissue.

Arterial System

As mentioned previously, the arteries of the body including the lower extremity supply the deliverables contained within the blood to body tissue. Major arteries of the lower extremity continually branch and divide into multiple and smaller vessels known as arterioles. As these arterioles reach the distal areas of the extremities, they are condensed and divided even further along their paths into microscopic versions of themselves known as capillaries. The major arteries that will be discussed will be the external iliac, femoral, popliteal, anterior tibial, posterior tibial, peroneal, dorsalis, and plantar arteries of the lower extremity (Gray, 1977).

External Iliac Artery

The aorta that stems from the heart itself splits into two arteries within the abdomen. These two arteries are known as the left and right common iliac arteries. These two arteries represent the left and right sides of the body as it divides into the legs of the lower extremity. Each common iliac artery diverges into the internal artery and its larger diameter external iliac artery counterpart within the pelvic region. It is from the external iliac artery that the femoral artery within each upper thigh region of the legs begins (Gray, 1977).

Femoral Artery

The femoral artery is the primary artery supplying blood to the legs (Yamamoto & Brada, 1996). Continuing his taxonomy of the vascular system, Gray (1977) reveals that the common femoral artery after leaving the external iliac artery maintains a close proximity to the femur and the hip within the proximal region of the upper thigh. This medial region of the upper thigh or groin region is known as the Scarpas's triangle. It is within the Scarpa's triangle that the femoral artery is closest to the surface of the skin and sometimes referred to as the superficial femoral artery. As it continues towards the middle of the thigh, it enters the region known as Hunter's canal. Here it is further away from the proximity of the femur bone. It is also in this region that a majority of its furcating occurs. Branches of the femoral artery are the superficial epigastric, superficial circumflex iliac, superficial external pudic, deep external pudic, and the profunda. The profunda femoris or deep femoral artery has three branches that extend the artery into the external circumflex, the internal circumflex and the four perforating arteries. At the inferior portion of the thigh near the popliteus muscle, the femoral artery passes through the adductor magnus muscle opening to become the popliteal artery.

Popliteal Artery

The popliteal artery is at the inferior portion of the thigh and continues in a longitudinal fashion past the posterior region of the knee to the inferior portion of the popliteus muscle. Branches of the popliteal artery are the superior and inferior muscular branches, the cutaneous, the superior internal and external articulars, the Azygos articular, and the inferior internal and external articulars. It is at the inferior portion of the popliteus muscle that the popliteal artery divides into the anterior and posterior tibial arteries (Gray, 1977).

Anterior Tibial Artery

The anterior tibial artery begins at the posterior segment of the knee below the popleus muscle. It penetrates amid the two heads of the tibialis posticus muscle and emerges on the anterior side of the lower leg through the gap of the interosseous membrane. The artery continues in an oblique path from the medial side of the fibula to the anterior side of the tibia. Branches of the anterior tibial artery include the posterior recurrent tibial, superior fibular, anterior recurrent tibial, muscular, and the internal and external malleolus. The anterior tibial artery concludes at the anterior curvature of the ankle joint where it becomes the dorsalis pedis artery (Gray, 1977).

Posterior Tibial Artery

The posterior tibial artery is a continuation of the popliteal artery that is superior to it at the posterior portion of the knee. Its path maintains an angle from the popliteus muscle towards the medial malleolus in the ankle. The journey of the posterior tibial artery ends with the branching of the internal and external plantar arteries. Additional branches of the posterior tibial artery are the peroneal, muscular, nutrient, and communicating arteries (Gray, 1977).

Peroneal Artery

The peroneal artery is a branch of the posterior tibial artery that began from the bottom of the popliteus muscle. Its origin is located on the lower leg's posterior side just below this muscle. It maintains an oblique course close to the posterior side of the fibula ending on the lateral posterior side of the heel in the external calcanean artery. Branches of the peroneal artery include the muscular, nutrient, anterior peroneal, communicating, and the posterior peroneal arteries (Gray, 1977).

Dorsalis Pedis Artery

The dorsalis pedis artery is a superficial artery that continues from the anterior tibial artery along the dorsal side of the foot. Its bifurcation produces the communicating and dorsalis hallucis arteries. Other branches of the dorsalis pedis include the tarsal and metatarsal-interosseous arteries (Gray, 1977).

Plantar Arteries

The plantar arteries are a group consisting of the internal and external plantar arteries. The internal plantar artery lies along the medial side of the foot's plantar surface. Its pathway sets off from the calcaneus in a linear manner towards the digital branch arteries of the first metatarsal and phalange. The external plantar artery, being consistently larger than its internal sibling is located on the plantar surface of the foot also. Its pathway traverses in an oblique manner around the lateral arch of the foot to the proximal portions of the metatarsals. Here is where it inosculates with the communicating artery to complete the plantar arch. Branches of the plantar arch include the posterior perforating and digital anterior perforating arteries (Gray, 1977).

Venous System

It should be noted that the venous system other than blood flow path, differs from the arterial system by having thinner blood vessel walls. This is due to the walls not containing a high amounts of muscular tissue. Blood vessel wall breadth continues to decrease as they progress away from the lower extremities towards the upper. The venous system also differs from the arterial in that it contains a larger number of blood vessels and therefore a larger quantity of blood (Gray, 1977). This may be of concern in prolonged static postures of standing or sitting where venous pooling in the lower legs and feet could lead to pain, varicose veins, and other illnesses (Messing, Tissot, & Stock, 2006).

Gray (1977) continues saying that the body's venous system is divided into pulmonary and systemic veins. Pulmonary veins return de-oxygenated (arterial) blood to left atrium of the heart from the lungs whereas systemic veins return un-oxygenated (venous) blood to the hearts right atrium from all of the capillaries. Systemic veins of the lower extremity (including abdomen and pelvis), empty their blood supply into the larger inferior vena cava that continues longitudinally along the spine towards the heart. These systemic veins consist of both superficial (cutaneous) and deep veins. Konz (1999) mentions that "Three venous systems drain the lower limbs: 1) a deep central system drains the muscles, 2) a superficial system drains the foot and the skin of the leg, and 3) a perforating system connects the deep and superficial systems" (p. 896). In addition, Gray (1977) mentions that both the superficial and deep veins of the lower extremity contain a higher number of valves that prevent blood backflow than does the upper extremity.

Superficial Veins

Venous system blood vessels are considered superficial veins when they are located near the surface of the body. Specifically, this location tends to be flanked by two layers of superficial fascia (integument). The two superficial veins located in the lower extremity are the long or great saphenous vein and the short or small saphenous vein. The long saphenous vein is located on the medial side of the legs. Its reach is from the medial malleolus to the deep femoral vein of the upper thigh. The short saphenous veins originate at the lateral portion of the dorsal side of the foot. It then wraps around the inferior part of the lateral malleolus and ascends at an oblique angle along the back of the lower leg to the posterior knee region. In this region the short saphenous vein penetrates between the superior origins of the gastrocnemius muscle and then terminates into the popliteal vein. Both versions of the superficial veins of the lower extremity have multiple branches that interweave themselves around the surface regions of the legs and feet (Gray, 1977).

Deep Veins

Similar to a surface drainage system on a street, superficial veins collect the blood from the surface locations and route it to their coordinated deep vein counterpart. Deep veins of the venous system tend to be located alongside their arterial counterparts throughout the body. This means that they are located within and between muscle groups and near skeletal bone. In addition, deep veins have wider vessel walls and contain a higher number of valves than the superficial veins. In the foot, are located the external and internal plantar veins. These veins amalgamate themselves with the posterior tibial vein and peroneal veins of the posterior lower leg. In conjunction, the anterior tibial veins join with the posterior tibial veins and peroneal veins by perforating between the tibia and fibula to the posterior region of the lower leg. From here they combine with the popliteal vein to perforate the adductor magnus and form with the femoral vein in the lower thigh. The femoral vein in turn, returns the venous blood to the external iliac vein that passes along the pelvic region's rim and merges with the internal iliac veins. This merger forms the common iliac veins that empty into the inferior vena cava. As stated previously, all the veins of the lower extremity, abdomen, and pelvis return the venous blood to the inferior vena cava that progress along the anterior surface of the spinal column of the back. In addition to the veins of the lower extremity and external pelvic regions, there are internal pelvic and abdominal veins that add to the blood supply such as the deep epigastric veins, the deep circumflex iliac veins, the internal iliac vein, internal pudic veins, haemorrhoidal plexus veins, vesico-prostatic plexus, and middle sacral veins (Gray, 1977).

Cost of Work-related Musculoskeletal Disorders

The cost of work related injuries and illnesses including WMSDs in 2003 was tabulated to be $50.8 Billion. This includes the cost of medical care as well as worker wages during time off from work (indemnities) (Liberty Mutual, 2005). When adjusted for inflation, there has been approximately a $1 Billion growth in injury cost since 1998 within the United States. To that end, safety is a major issue to employers. In a survey conducted by Liberty Mutual (2005) of industry senior financial executives about company investment into injury prevention, more than 60% mentioned that for every dollar invested into prevention, $2 or greater was shown in their returns. They also revealed that overexertion and repetitive motion were the top two causes of their worker compensation issues.

The sixth annual Liberty Mutual Workplace Safety Index reported that in 2003 overexertion was the greatest cause of WMSDs in the United States (26.4% of injuries) (Liberty Mutual, 2005). This hazard resulted in a $13.4 Billion impact on the industry with a growth in cost of 15.1% since 1999. Liberty Mutual's report also confirmed that the sixth highest cause of WMSDs was repetitive motion (5.9% of injures) whose industry impact was estimated at $3 Billion with a national cost decrease of 2.2% since 1999.

Biddle and Roberts mention that the Ergonomic Program Standard suggested by the US Occupational Safety & Health Administration (OSHA) in 1999 estimated the mean cost of a work-related MSD case to be $22,546 (Biddle & Roberts, 2004). The 2007 edition of Injury Facts produced by the National Safety Council has a greater amount of detail in relation to WMSDs. A portion of their report for the 2003-2004 mean cost to industry per incident is refined by cause or event, nature of injury, and part of the body. Their cost estimates include the medical costs of the injury/illness and the indemnity involved and is based on insurance reports from the National Council on Compensation Insurance.

Reported case causes involving the discipline of WMSDs include that of cumulative trauma and strain whose costs averaged at $17,013 and $18,600, respectively. For nature of the injury/illness, Injury Facts shows that infection/inflammation cases average $14,696, occupational disease/cumulative injury at $16,678 and sprain/strain at $17,506. Mean cost to region of the body is also noted within the report although cause and nature of the injury are not involved in the resultant dollar amount. If focusing on the LE regions in particular, the report shows that the highest cost is to the leg region with the amount being $24, 339, followed by hip/thigh/pelvis ($20,830), knee ($18,495), ankle ($12,518), and foot/toe regions ($10, 233) (National Safety Council, 2007). Unfortunately detail illustrating costs to industry, specifically for WMSDs to the LE region within the United States is scarce if not nonexistent.

Incident Rates for Lower Extremity Work-related Musculoskeletal Disorders

In order to better understand the cost impact on economy, one must first understand the statistics behind the incidents themselves. The prevalence of injury/illness to specific body locations over a period of time, the rate at which they occurred (incident rate), and the median number of days away from work due to the injury are each important pieces of information necessary for assessing heath concerns. Cumulative WMSDs represent a large source of the disorders and disabilities that occur at the workplace (Chaffin, Andersson, & Martin, 1999). Chaffin et al. (1999) goes on to state that in 1988 the Bureau of Labor statistics reported approximately 6.2 million occupational injuries of which, approximately 3 million required days away from work or work-task restriction. Of the incidents recorded, 31.2% were from overexertion, 23.6% from being struck by or against an object, and 17% from falls. 43% of those injuries were due to sprains and strains to the MSD systems and of this grouping, 7.9% were knee related and 7.0% were ankle related.

Today, on an annual basis, the BLS continues to collect labor data from the occupations of the private sector for the United States Department of Labor (Bureau of Labor Statistics, 2006a). One of the most fairly recent data available for injuries and illnesses involving days off from work is from 2005. Of the 1,234,680 cases reported for that year, 375,540 were considered WMSD-related with approximately 64% happening to males and the remainder to females (Bureau of Labor Statistics, 2006b). The BLS (2006b) gives further information into the types of industries that are at risk for WMSDs. These industries include those that produce goods and those that provide a service. The data does not include information from the military, professional athletics, or performing arts which are also occupations susceptible to WMSDs (Donovan & Black, 1986). Almost three-fourths of the WMSDs were within the Service Providing industries (70%), with the remainder being the Goods Producing sector (30%). The three largest of the Service Providing industries' incidents occurred in Trade Transportation and Utilities with 125,430 followed by Educational and Health Services at 75,350 and Health Care and Social Assistance with 72,780. For the Goods Producing industry, the majority of incidents occurred in Manufacturing (69,130) and Construction (35,900).

The BLS' (2006b) records for LE WMSDs of the same year (2005) were 3.2 incidents per 10,000 full-time workers totaling at 29,390 cases, with a median sum of days off work being 11 (relative standard error of 1.5). The total cases from the 2005 data are slightly higher than the previous year of 2004 (28,770 cases), yet still lower than the total cases from 2003 (33,590). In addition, the incidence rate of 2005 remains the same as 2004 at 3.2 per 10,000 full-time workers. This 3.2 rate from 2004 and 2005 is lower than that from 2003's 3.8 per 10,000 full-time workers. The relationship of recorded cases to major industry can be seen in Table 2-2. Their distribution between the Goods Producing industries and the Service Providing ones continues to resemble that of the whole body WMSD cases mentioned previously. Table 2-3 gives additional information as to the regions and joints considered by the BLS to be WMSD related.

Table 2-2 Lower Extremity occupational ergonomic illnesses noted in the 2005 BLS data by Major Industry. Adapted from the Bureau of Labor Statistics (2006b)

Major Industry	**Total Cases**	**Incidence Rate** (Per 10,000 Full-time Workers)	**Median Days Away From Work**	**Relative Standard Error**
All Industry	29,390	3.2	11	1.5
Goods Producing Industries	8,040	3.6	13	2.5
Natural Resources and Mining	750	5.0	10	6.8
Construction	3,280	5.0	13	5.3
Manufacturing	4,000	2.8	13	3.0
Agriculture, Forestry, Fishing, and Hunting	330	3.7	5	14.2
Mining	420	6.9	25	5.6
Service Providing Industries	21,360	3.1	10	2.0
Trade, Transportation, and Utilities	11,090	5.0	14	2.8
Information	480	1.7	24	9.2
Financial Activities	690	1.0	5	9.8
Professional and Business Services	2,250	1.8	5	7.7
Educational and Health Services	4,600	3.6	9	4.1
Leisure and Hospitality	1,570	1.9	14	8.4
Other Services Except Public Administration	670	2.3	12	9.9
Wholesale Trade	1,750	3.2	10	7.0
Retail Trade	5,100	4.2	14	4.5
Transportation and Warehousing	4,010	10.0	14	4.3
Utilities	230	4.2	19	11.6
Finance and Insurance	120	0.2	5	19.1
Real Estate and Rental and Leasing	570	3.2	6	12.5
Professional and Technical Services	750	1.2	5	13.3
Management of Companies and Enterprises	140	0.9	5	23.5
Administrative and Waste Services	1,360	3.0	5	10.5

Table 2-3 2005 Bureau of Labor Statistics MSDs by Lower Extremity Location. Adapted from the Bureau of Labor Statistics (2006b)

BLS Code #	Part of Body Affected	Total Cases	Incidence Rate	Median Days Off Work	Relative Standard Error
251	Hip(s)	2,070	0.2	5	5.2
4	Lower Extremities Total	29,390	3.2	11	1.5
41	Leg(s)	22,770	2.5	13	1.7
410	Leg(s) - unspecified	1,700	0.2	4	5.8
411	Thigh(s)	590	0.1	6	9.8
412	Knee(s)	19,170	2.1	14	1.8
413	Lower leg(s)	1,010	0.1	7	7.4
418	Multiple leg(s) locations	270	0.0	25	14.3
419	Leg(s)- n.e.c.	30	0.0	19	41.1
42	Ankle(s)	4,840	0.5	6	3.5
43	Foot(feet) – except toe(s)	1,290	0.1	9	6.6
430	Foot(feet)- except toe(s)- unspecified	1,060	0.1	8	7.3
432	Sole(s)	150	0.1	14	19.3
4321	Balls(s)	20	0.0	16	47.7
4323	Heels(s)	110	0.0	15	22.4
438	Multiple foot(feet) locations	20	0.0	72	52.1
439	Foot(feet)- n.e.c.	60	0.0	14	30.9
44	Toe(s)- toenail(s)	60	0.0	2	29.8
48	Multiple lower extremities locations	400	0.0	23	11.9
481	Foot(feet) and leg(s)	30	0.0	29	39.9
482	Foot(feet) and ankle(s)	80	0.0	38	26.3
489	Multiple lower extremities locations- n.e.c.	260	0.0	25	14.6
49	Lower extremities- n.e.c.	20	0.0	25	47.8

Considering that the initial version of the LERA model is for the knee, a more detailed inspection between 2003 and 2005 can be mentioned. As Table 2-3 displays, knee cases for 2005 amounted to 19,170, with an incidence rate of 2.1 cases per 10,000 full-time employees. In addition, 2004 data revealed 19,320 cases with an incident rate of 2.2 per 10,000 full-time employees. 2003 had 21,230 cases with an incident rate of 2.4. Median lost work days for each of these years was 14, 19, and 19 for 2005, 2004, and 2003, respectively (Bureau of Labor Statistics, 2005a, 2005b, 2006b).

Lower Extremity Work-related Musculoskeletal Disorders

Soft tissue disorders pertaining to the lower extremity tend to generally result as soreness, bursitis, tendonitis, sprains, strains, tears, rheumatism, ganglion cysts, and fractures (Bureau of Labor Statistics, 2006b). In the case of cumulative occupational disorders, studies have shown that although many of the listed injuries are more likely to occur in athletic and military operations, industry settings of less intensity still are susceptible to these disorders occurring. References with indication to an industry or occupation outside of the higher intensity athletic areas were the primary indicators for inclusion in this review. Secondary to this stipulation, are postural activities that are known to be risks or are of concern in industry settings.

Muscular System WMSDs

WMSDs of the musculoskeletal systems tend to be under continuous research for the athletic and military industries. This is understandable due to the fact that a majority of the injuries and disorders noticed occur under high intensity situations with large quantities of forces, durations of exposure, and repetitions. In particular, what is difficult to find are studies of these same disorders that are in other occupations and industries but are not under the influence of the same high intensity exposures. The disorders of iliotibial band syndrome and plantar fasciitis are two disorders that either happen to have incidents in occupations outside athletics and military or have postural activities that are universally used in occupations as a whole.

Iliotibial Band Syndrome

The most frequent complaint of later knee pain can be pin pointed to iliotibial band friction syndrome (ITBFS) (Biundo, Irwin, & Umpierre, 2001)which is more commonly referred to as just iliotibial band syndrome (ITBS) (Martinez & Honsik, 2006). Discomfort from ITBS may not only be noticed along the lateral portions of the knee but may also be noticed along the lateral locations of the hip and anywhere in between (Adkins & Figler, 2000). Pain location typically associates to the origin of the syndrome. For ITBS, this origin can be at either of two places, the trochanteric bursa of the hip or the lateral femoral epicondyle.

Inflammation of the trochanteric bursa is known as trochanteric bursitis which is caused by blunt trauma to the bursa or by high repetitions due to activity (Adkins & Figler, 2000). Adkins and Figler (2000) mention that trochanteric bursitis is a separate condition of ITBS and is not directly related but may sometimes be initially mis-diagnosed as ITBS due to pain being located at that region of the LE. The authors also note that the addition of a snapping feeling along the iliotibial band as the hip moves through flexion and extension motions during an Ober's test are a positive indication of ITBS. The lateral femoral epicondyle is the area where impingement can also occur and cause pain during knee flexion and extension (Adkins & Figler, 2000; Martinez & Honsik, 2006; Nishimura, Yamato, Tamai, Takahashi, & Uetani, 1997).

Occupations that are normally seen affected by this are those in athletics or military where long distance running and cycling activities are usually seen (Kelly & Winston, 1994; Martinez & Honsik, 2006; Nishimura et al., 1997). Additionally, ITBS also has been noted to affect tennis players (Martinez & Honsik, 2006), skiers, weight lifters, and activities involving jumping (Nishimura et al., 1997).

High recurrence rates of knee flexion and extension has been known to be a primary occupationally related cause for ITBS (Biundo et al., 2001; Martinez & Honsik, 2006; Nishimura et al., 1997). This repetitive movement Biundo et al. (2001) explain, is what leads to tissue inflammation of the iliotibial band. Nishimura et al. (1997) add to this occupationally related risk by declaring that tasks involving high repetitions of transitions between squatting and standing is one simple but common example. Occupationally related variables are not the only risks that should be of concern for this disorder though. Like many other disorders noted throughout this review, personal variables may predispose a person's likelihood of this developing. Such factors include excessive medial tibial rotation during movement, a disproportionate level of bowleg at the knees (genu varum), or foot overpronation (Martinez & Honsik, 2006). Nishimura et al. (1997), also state that discrepancies between leg lengths may also add to ITBS predisposition.

Plantar Fasciitis

The plantar fascia functions as arch support for the foot as well as a form of shock absorption from walking, running, and jumping (Singh, 2006). Tension along the plantar fascia along the inferior side of the foot can lead to pain and discomfort from the disorder called plantar fasciitis. Plantar fasciitis is known to be the leading cause of foot pain in people (Barrett & O'Malley, 1999). Barrett and O'Malley (1999) mention that the pain is normally pinpointed at the region of the underside of the foot near the medial calcaneal tubercle but can also radiate distally along the plantar fascia towards the toes as well. Patient complaints of plantar fasciitis note that these pains are noticed with the first steps of the day after waking up with discomfort lessening as more walking activity occurs (Barrett & O'Malley, 1999; Huang, Qureshi, & Biundo, 2000). Pathophysiology of the fascia reveals that pain is not caused by inflammation as the term fasciitis commonly infers (Hurwitz, 2004; Singh, 2006; Young, Rutherford, & Niedfeldt, 2001). Instead, it is more of a degenerative course of action (similar to tendonosis) caused by exposure to repeated micro tears in the fascia (Young et al., 2001). Evidence of degeneration Hurwitz (2004) says, is noticed under microscopic observation of the affected area where signs of this micro trauma leave proof of degraded type 1 collagen fibers, chondroid metaplasia, angiofiboblastic proliferation, and fibrocyte necrosis. He continues on saying that employee cases pursuing plantar fasciitis for worker's compensation may have issues due to it legally being seen as a degenerative disorder versus a WMSD.

Causes of the initiation of plantar fasciitis can range from running activities (Singh, 2006) to geriatric regression of healing capability and reduction in elasticity of the plantar fascia (Huang et al., 2000; Hurwitz, 2004; Riddle, Pulisic, Pidcoe, & Johnson, 2003). Aside from changes in running activity patterns (such as increased speed or duration), further evaluation of exposures that may increase other weight bearing activities such as an increasing excess of walking or prolonged standing may also be to blame (Riddle et al., 2003; Singh, 2006; Young et al., 2001). Riddle et al (2003) finds that this relationship has an Odds Ratio of 3.6 (95% CI: 1.3-10.1). Unfortunately, none of these studies refer to a particular amount or range of exposure time before onset of disorder. This is likely due to high subjectivity.

The personal risks related to plantar fasciitis are numerous in comparison to their occupational counterparts. Anatomical and biomechanical deficiencies such as low arched (pes planus) (Hurwitz, 2004; Singh, 2006; Young et al., 2001) and high arched (pes cavus) (Hurwitz, 2004; Young et al., 2001) feet are two factors involved. Pes planus as explained by Singh (2006), may cause high amounts of foot pronation. Hurwitz (2004) adds additional detail to Singh's statement by mentioning that the foot pronation is for the hindfoot and that the forefoot actually creates excessive abduction. He continues with the explanation of pes cavus and that due to its high inflexibility, it constrains the hindfoot's pronation capacities and causes increased tension on the plantar fascia. Other personal factors mentioned by Young et al. (2001) are differences in leg lengths, too much lateral tibial torsion, and high amounts of femoral anteversion. The authors also point out that tight muscles of the triceps surae (includes the gastrocnemius and the soleus calf muscles) combined with tight Achilles tendons and foot muscles are also variables. These tight muscle groups are noted by sources to cause limitations to ankle dorsiflexion (Hurwitz, 2004; Riddle et al., 2003; Singh, 2006). In fact, Riddle et al. (2003) observes an increasing connection with decreasing dorsiflexion capability. Their findings show a decreasing but associated range of dorsiflexion of 6-10° as the initial bond (OR = 2.9, 95% CI: 1.6-5.0) and 0° or less as the worst (OR = 23.3, 95% CI: 4.3-124.4). Singh

(2006) and Riddle et al. (2003) also talk about body weight, in particular, obesity being another possible cause. Obesity for adults is considered to be a Body Mass Index (BMI) score of 30 or greater (Center for Disease Control, 2007). Riddle et al. (2003) also observed an increasing relationship with BMI and risk of plantar fasciitis. BMI scores of 27.5 (55-66 pounds over normal weight) had a preliminary linkage (OR = 2.0, 95% CI: 1.28-3.08) while those participants with a BMI of 35 or greater (66 pounds or more over normal weight) had a greater correspondence (OR = 5.6, 95% CI: 1.9-16.6). Tables 2-4 and 2-5 show a combined view of the occupational and personal risks involved with both ITBS and plantar fasciitis.

Table 2-4 LE muscular disorder occupational risk variables

	Occupational Risks		
Muscular Disorder	Prolonged Standing	Excessive Walking	Squat to Stand Movement
Iliotibial Band Syndrome			X
Plantar Fasciitis	X	X	

Table 2-5 LE muscular disorder personal risk variables

	Muscular Disorder	
Personal Risks	Iliotibial Band Syndrome	Plantar Fasciitis
Leg Length Discrepancy	X	X
Excess Lateral Tibial Rotation		X
Excess Medial Tibial Rotation	X	
Genu Varum (Bow Legged)	X	
Pes Planus (Low Foot Arch)		X
Pes Cavus (High Foot Arch)		X
Foot Overpronation	X	
Excess Femoral Antiversion		X
BMI ≥ 30		X
Dorsiflexion Displacement < 10°		X

Skeletal System WMSDs

LE WMSDs do transpire for the skeletal system as well. Although the majority of injuries happen to be acute and accidental in nature, occurrence of cumulative bone fractures is still possible. These are known as stress fractures and can take place anywhere along the LE. Place of occurrence is highly dependent on occupational and task usage as stress fractures area known to occur as a sign of overuse or over exposure to risk variables.

Stress Fractures

Stress fractures are noted by literature to typically occur in environments that are exposed to high forces and/or high repetitions (Donovan & Black, 1986; Laker & Sullivan, 2006; Rauh, Macera, Trone, Shaffer, & Brodine, 2006; Warden, Burr, & Brukner, 2006).

Warden et al. (2006) mention that bone typically fails or fractures when a single load strain rate is 10,000 $\mu\varepsilon$ or higher. They present the normal range of bone strain to be 400-1500 $\mu\varepsilon$ and that damaging strains that causes micro-fractures exceed the normal ranges but is less than the single load failure limit. In order for these micro-fractures to evolve into a stress fracture, they must consistently transpire repeatedly over a short duration of time that exceeds the healing rates of the bone itself (Laker & Sullivan, 2006; Warden et al., 2006). A study (n = 111) performed in the realm of athletic sports, found that of the 26 stress fractures observed, 46% occurred for the tibia, 15% for the navicular (tarsal) bone of the foot, and 12% for the fibula bone (Bennell, Malcolm, Thomas, Wark, & Brukner, 1996). The authors' results found no dissimilarity between the genders for causes ($p > 0.05$). An interesting result of the study noticed that stress fractures of different LE body segments related to different sport events. Distance running for example related to long bone and pelvic stress fractures whereas sprinters and jumpers had more foot related stress fractures ($p < 0.05$). This makes sense because in another study detailing military basic training (long distance running), 71% of the stress fractures occurred to the tibia bone and 25% to the femur (Giladi, Ahronson, Stein, Danon, & Milgrom, 1985). Another review of stress fractures in military recruits found an increase in the rate of stress fracture incidents during weeks of high marching instead of field training (Jordaan & Schwellnus, 1994). Figure 2.8 is an example of the pathophysiology proposed by Warden et al. (2006).

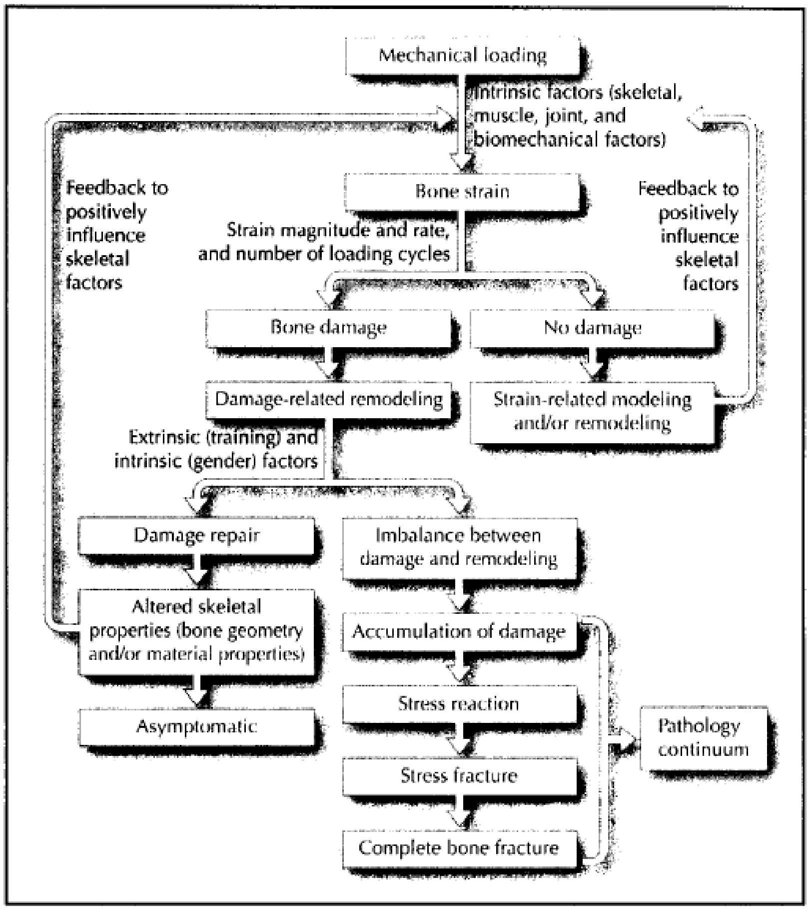

Figure 2.8 Pathophysiology of a stress fracture model. With kind permission from Springer Science+Business Media: Current Osteoporosis Reports, Stress Fractures: Pathophysiology, Epidemiology, and Risk Factors, 4, 2006, page 104, Stuart J. Warden, David B. Burr, Peter D. Brukner, figure 1.

Athletic and military occupations continuously show signs of stress fracture incidents (Donovan & Black, 1986; Rauh et al., 2006; Warden et al., 2006). Athletes such as runners and swimmers are reported to be susceptible to stress fractures (Donovan & Black, 1986). Rauh et al. (2006) conducted studies on female military recruits in the United States Marines and noted that lack of menstrual cycles associated to episodes of stress fractures. Donovan and Black' (1986) review of the literature found that medical practitioners (such as nurses and physicians), ballet dancers, waitresses, and wallpaper hangers are other occupations that have shown signs of stress fracture incidents.

Aside from high intensity running and jumping activities, the number of occupational factors leading to development of stress fractures is low. These types of activities rarely occur outside of the athletic and military environments. Oddly enough, a study was found that related to a wallpaper hanging occupation (Donovan & Black, 1986). The result of the study found that a knee flexion posture was utilized by the worker that developed the disorder in the second metatarsal of one of his feet. Further investigation revealed that the majority of the weight bearing was endured by the fore foot while both the foot and toes were in dorsiflexion positions. Continuous exposure to this posture eventually produced the stress fracture.

The number of personal factors far outnumbers that of the occupational ones. Biomechanically, discrepancy in leg length (Bennell et al., 1996), a narrow tibia ($p < 0.001$), high hip external rotation ($p = 0.016$) (Giladi, Milgrom, Simkin, & Danon, 1991), and Q-angles greater than 15° (Relative Risk = 5.4, $P = 0.008$) (Cowan et al., 1996) all individually are contributable. Additionally, metatarsal stress fractures are more likely to be associated to low arched feet while high arched feet have more of an affect on the femur and tibial bones (Simkin, Leichter, Giladi, Stein, & Milgrom, 1989). Low physical fitness is also seen as a contributor to the susceptibility of developing a stress fracture (Jones, Thacker, Gilchrist, Kimsey, & Sosin, 2002; Warden et al., 2006) and high fitness is shown to even be preventive for a female study of US army recruits (RR = 0.66, 95% CI: 0.53-0.83) (Lappe, Stegman, & Recker, 2001). Amenorrhea is a medical diagnosis given to women who have not had a menstrual cycle for several months (Rauh et al., 2006). Rauh et al. (2006) further mentions that secondary amenorrhea (more than 6 consecutive months without menstrual activity) is noticed to have an affect on the female skeletal system and has shown association to stress fracture development (RR = 2.7, 95% CI: 1.1-6.9). The risks are summed together in Table 2-6, which shows the personal and occupational risks that lead to stress fractures.

Table 2-6 Risk variables associated to LE stress fractures

Risk Type	Risk Variable	Source
Occupational	Cumulative Loading on a LE region	Donovan & Black, 1986
Personal	Leg Length Discrepancy	Bennell et al., 1996
Personal	Narrow Tibia	Giladi et al., 1991
Personal	Excessive External Hip Rotation	Giladi et al., 1991
Personal	Q-angles > 15°	Cowan et al., 1996
Personal	Low Physical Fitness	Jones et al., 2002; Warden et al., 2006
Personal	Secondary Amenorrhea (women)	Rauh et al., 2006

Nervous System WMSDs

WMSDs of the LE also include damage to the nervous system. These disorders are typically called neuropathies. A majority of the neuropathies in literature are results of acute traumatic injury resulting from accidents. This review section pertains to those neuropathies that occur in an occupational setting and/or is associated to having developed chronically from prolonged exposure to occupational body postures, limb positions, or activities that occur in workplace environments. In addition, if literature's etiology of the disorder also includes personal risk variables such as anthropometric anatomical structure discrepancies or health concerns such as diabetes or pregnancy, then it was included. Based on the assessment of the literature, five disorders will be discussed that can be interpreted as LE WMSDs. These nerve entrapments transpire along different regions of the leg and include entrapments to the lateral femoral cutaneous nerve branch, the common peroneal nerve branch, the superficial peroneal nerve branch, the deep peroneal nerve branch, and the digital nerve branches of the foot's dorsum (Figure 2-9).

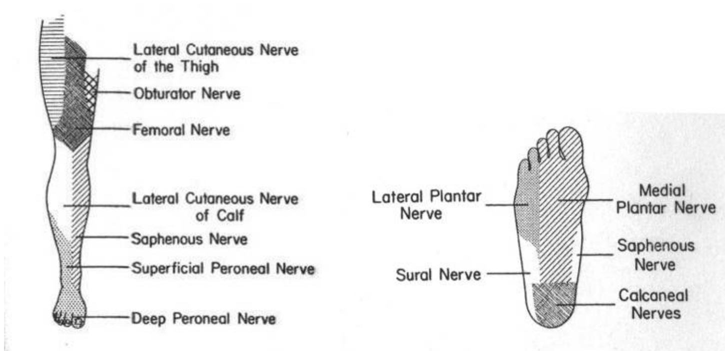

Figure 2.9 Leg and foot nervous system associations to the regions of the LE that they affect. Reprinted with permission from Hadler, N.M., Occupational Musculoskeletal Disorders, Lippincott-Raven Publishers, 1993.

Lateral Femoral Cutaneous Nerve Entrapment

Lateral femoral cutaneous nerve entrapment is a common neuropathy involving the nerve branch of the same name. This disorder affects the lateral and anterolateral regions of the thigh (Hollis, Lemay, & Jensen, 2005)and may sometimes also be referred to as meralgia peresthetica (Hadler, 1993; Hollis et al., 2005)or Bernhardt's disease (Hadler, 1993). The lateral femoral cutaneous nerve begins from the lumbar spinal chord regions and progresses anteroinferiorly towards the superior lateral thigh region (Fargo & Konitzer, 2007; Hollis et al., 2005; Kornbluth & Marone, 2006). It is used for sensory perception and does not serve any muscular motor units (Kornbluth & Marone, 2006; Sekul, 2007). Symptoms include peresthesia (numbness, tingling, and prickling) and burning (Hadler, 1993; Hollis et al., 2005; Kornbluth & Marone, 2006; Sekul, 2007).

Compression from lying down on one's side in a fetal position has shown a relationship to this neuropathy (Sekul, 2007). Postures or activities that require leaning or pushing against an object or work surface with the lateral side of the upper thigh, over long durations and repetitive exposures can also be a risk (Feldman, Goldman, & Keyserling, 1983). Feldman et al. (1983) furthermore noted postures using prolonged hip abduction to be a possibility (Table 2-4). Additional postures such as prolonged standing (Fargo & Konitzer, 2007; Hollis et al., 2005; Sekul, 2007), or hip extension (Fargo & Konitzer, 2007) can exacerbate the symptoms. In a study performed by Kho et al. (2005), lateral femoral cutaneous nerve entrapments were found to be associated to prolonged and repetitive exposure to walking and cycling activities. Activities such as walking may also exacerbate the symptoms whereas sitting may relieve them (Hollis et al., 2005; Sekul, 2007).

Occupational causes can also be due to apparel compression such as tight clothing (Fargo & Konitzer, 2007; Hadler, 1993; Hollis et al., 2005; Kho, Blijham, & Zwarts, 2005; Sekul, 2007) body armor (Fargo & Konitzer, 2007), or tight waist belts (Hollis et al., 2005; Kornbluth & Marone, 2006) and/or utility belts such as those commonly used in policing, military, or carpentry occupations (Tables 2-9 and 2-10) (Fargo & Konitzer, 2007; Feldman et al., 1983). Personal risks include weight gains from pregnancy or obesity (Hollis et al., 2005; Kho et al., 2005; Kornbluth & Marone, 2006; Sekul, 2007), diabetes (Hollis et al., 2005; Kornbluth & Marone, 2006; Sekul, 2007), and leg length discrepancies (Table 2-8) (Hollis et al., 2005). In addition, Kornbluth and Marone (2006) noted that overt alcohol usage and thyroid disorders can contribute to this neuropathy.

Common Peroneal Nerve Entrapment

Common peroneal nerve entrapment has been noted to be a common neuropathy issue for the LE due to it generally happening as a result of a traumatic injury (Hadler, 1993; Hollis et al., 2005). The common peroneal nerve travels along the lateral-posterior portions of the leg as it traverses the knee region from the thigh into the lower leg. Symptoms of this entrapment such as pain, typically goes unnoticed and if it does exist, may be more related to the acute injury that caused it (Hollis et al., 2005). In chronically produced situations, nerve tapping such as that produced in a Tinel sign test may produce pain along the nerve branch.

Compression from repetitive leg crossing while in sitting postures are associated to a chronic onset of symptoms (Kaminsky, 1947; Nagler & Rangell, 1947). Another chronically producing method can be prolonged squatting postures (Table 2-7) (Hollis et al., 2005). In this latter situation, Hollis et al. (2005) mention that this resulting nerve compression is referred to as strawberry picker's palsy. This inference is based on the occurrences in farming industries while performing harvesting or hoeing tasks (Koller & Blank, 1980; Seppalainen, Aho, & Uusitupa, 1977). Use of the superior lateral portions of the lower leg against a work surface for machine control or for leaning is an additional risk (Feldman et al., 1983). Occupations that typically use these postures aside from farming industries include mining, shoe sales (Spaans, 1970) and even catchers from baseball (Table 2-10) (Feldman et al., 1983).

Also revealing, is that of the personal health concerns for these working populations. For instance, diabetes mellitus (Hollis et al., 2005; Mulder, Lambert, & Bastron, 1961), hyper thyroidism, vasculitic disorders, leprosy as well as other conditions are all mentioned (Hollis et al., 2005). Furthermore, another study found that weight loss was also of concern, especially in combination with prolonged and repetitive leg crossing while bedridden in a hospital (Table 2-8) (Katirji & Wilbourn, 1988).

Interesting enough, required occupational equipment can also cause disorders when worn for long periods of time repeatedly. Coal mining and floor laying are two occupations that use knee pads due to prolonged kneeling exposure. In one study, the compression caused by the straps of the knee pads at the back of the knee were found to be causing common peroneal nerve entrapment (Tables 2-9) (Garland & Moorhouse, 1952). These varying causes and associations may lead to idiopathic diagnoses (Hollis et al., 2005) (similarly found in tarsal tunnel syndrome diagnoses).

Superficial Peroneal Nerve Entrapment

The superficial peroneal nerve branches along the lateral portions of the lower legs. Symptoms of entrapment entail categories of peresthesia (tingling, numbness, or prickling) (Hollis et al., 2005). Hollis et al. (2005) continue by mentioning that nerve entrapment along the superficial peroneal nerve may be due to it stretching during tasks that involve prolonged kneeling and squatting postures (Table 2.7).

Deep Peroneal Nerve Entrapment

Deep peroneal nerve entrapment is a disorder that affects the associated nerve branch of the same name. This branch travels along the anterior portions of the lower leg across the ankle and onto the dorsum of the foot. Symptoms may include pain, cramping, and burning along the dorsum of the foot (Hollis et al., 2005). Hollis et al. (2005) notes that postural associations have been made to floor sitting postures due to the compression dealt to the nerve branch (Table 2-7). Particular attention has been made to prolonged or repetitive sitting on the legs during full knee flexion with the feet in plantar flexion. This posture is also known to cause discomfort for the LE (Chung, Lee, & Kee, 2003). Apparel is also of concern for this disorder. In particular, high heeled shoes are known to put the foot in plantar-flexion and compel the toes into dorsiflexion. This is also a risk for neuropathic entrapment development (Table 2-9) (Borges, Hallett, Selkoe, & Welch, 1981).

Digital Nerve Entrapment

The superficial and deep peroneal nerves eventually lead to the dorsum of the foot creating the digital or interdigital branches along the tarsals and metatarsals. Nerve entrapment for the foot was briefly mentioned by one review (Feldman et al., 1983). The authors suggest that the combined postures of kneeling with hyperextended toes in tight shoes may be a hazard.

Table 2-7 Postures that may be plausible causes for developing nerve entrapments

	Postures (Occupational Risks)					
Nerve Entrapment	Imbalanced Leaning Against a Work Surface	Leg Crossing	Floor Sitting	Crouching or Squatting	Kneeling	Lying Down
Lateral Femoral Cutaneous	X					X
Common Peroneal	X	X		X		
Superficial Peroneal				X	X	
Deep Peroneal			X			
Digital *					X	

Use of a * denotes the marked posture with additional variables such as tight shoes and/or hyperflexed toes for digital nerve entrapment.

Table 2-8 Personal health risks that may be plausible causes for developing nerve entrapments

	Personal Risks					
Nerve Entrapment	LE Anthropometric Discrepancy	Diabetes	Sudden Weight Loss	Sudden Weight Gain	Vasculitic Disorders	Thyroid Disorder
Lateral Femoral Cutaneous	X	X		X		X
Common Peroneal		X	X		X	X

Table 2-9 Equipment that may be plausible causes to developing nerve entrapments

	Apparel or Equipment Risks					
Nerve Entrapment	Tight Clothing	Tight Waist Belts	Utility Belts	Torso Body Armor	Knee Pads	High Heeled Shoes
Lateral Femoral Cutaneous	X	X	X	X		
Common Peroneal					X	
Deep Peroneal						X

Table 2-10 Occupations reported to have incurred a LE nerve WMSD

Nerve Entrapment	Occupation	Source
Lateral Femoral Cutaneous	Police	Fargo & Konitzer, 2007; Feldman et al., 1983
	Military	Fargo & Konitzer, 2007; Feldman et al., 1983
	Carpentry	Fargo & Konitzer, 2007; Feldman et al., 1983
Common Peroneal	Farming	Hollis et al., 2005; Koller & Blank, 1980; Seppalainen et al., 1977
	Mining	Spaans, 1970
	Shoe sales	Spaans, 1970
	Athletic (Baseball Catcher)	Feldman et al., 1983

Vascular System WMSDs

Although not as prevalent as joint WMSDs, vascular system WMSDs do still occur. Of the literature reviewed, three types of WMSDs stand out as being possibly related to occupational environments. These are ischemia, vibration syndrome and varicose veins. These types of disorders develop due to prolonged and repeated exposure to vibration, tissue compression, or postural activity risks.

Ischemia

When the blood vessels of the body become constricted (vasoconstriction) and blood supply begins to diminish to the surrounding tissue, it is known as ischemia (Thomas, 1993). Feldman et al. (1983) mentions that prolonged sitting on small seats (stools, workbenches or tractor seats) can lead to development of ischemia. The authors state that this is due to the combination of body weight and improper seat size compressing the blood vessels against the sciatic notch.

Vibration Syndrome

Vibration syndrome is a result of exposing the body to vibrations from tools or environments for repeated prolonged durations. Vibration syndrome although typically referencing the hands of the upper extremity, affects the feet of the lower extremity as well. Foot and toe vibration syndrome has shown similar causes and symptoms to other disorders such as vibration white finger (VWF) and Raynaud's phenomenon or syndrome. Vibration syndrome has been shown to occur not just through direct foot contact to vibrating surfaces but also through hand-arm tool vibrations whose affects are transmitted to the feet. Hand and arm vibration has been shown to activate the sympathetic nervous system (part of the autonomic nervous system). The result of this activation is the constriction of the vascular system affecting both the hands and the feet (Sakakibara et al., 1991; Sakakibara, 1994; Sakakibara & Yamada, 1995). The studies mention that symptoms of vibration syndrome can be identified with lower foot skin temperatures during exposure and complaints of cold feet from the participants. In addition, prolonged exposure over time produces pathological changes to the vascular physiology in the toes (Hashiguchi, Yanagi, Kinugawa, Sakakibara, & Yamada, 1994; Sakakibara, 1994). Hashiguchi et al. (1994) found the association of vibrating tool usage to physical changes to be significant for toes and fingers ($p < 0.001$). Examples of these changes can be arterial thickening and/or perivascular fibrosis in the toes. Correlation from this same study revealed that symptoms in the fingers from hand-arm vibrating tools significantly ($r = 0.657$, $p < 0.001$) were related to symptoms found in the toes of the foot.

Occupations that have shown association to VWF of the foot are chainsaw operators (Hashiguchi, Sakakibara, & Yamada, 1990; Hashiguchi et al., 1994; Matoba, Chiba, & Sakurai, 1985; Sakakibara et al., 1991; Sakakibara, 1994; Toibana, Ishikawa, Sakakibara, & Yamada, 1994), bush cutters, grinders (Hashiguchi et al., 1994), rock drillers, quarries, and welders (Toibana et al., 1994). Another job noticed in literature, involved a wagon driver for a mink farm (Tingsgard & Rasmussen, 1994). The authors point out that the 46 year old man, used his left foot on the vibrating pedal of the wagon two or three hours per day for 12 years. The latter example as well as rock drilling are shown to be examples of direct foot contact to vibrating surfaces whereas the others previously listed are strictly hand-arm vibration tools. These occupations are listed also in Table 2-11.

Table 2-11 Occupations involving usage of vibrating tools that have association to vibration syndromes

	Occupation						
Source	Chainsaw Operator	Rock Driller	Quarrier	Welder	Bush cutter	Grinder	Wagon Driver
Hashiguchi et al., 1990	X						
Hashiguchi et al., 1994	X				X	X	
Matoba et al., 1985	X						
Sakakibara et al., 1991	X						
Sakakibara, 1994	X						
Sakakibara & Yamada, 1995							
Tingsgard & Rasmussen, 1994							X
Toibana et al., 1994	X	X	X	X			

Varicose Veins

LE varicose veins could be deemed as the most prevalently researched LE WMSDs affecting the vascular system whose treatment results in surgery (Laurikka, Sisto, Tarkka, Auvinen, & Hakama, 2002). Although termed under the general label of varicose veins, there are actually three forms of varicose veins; trunk, reticular, and hyphenwebs (Stvrtinova, Kolesar, & Wimmer, 1991). The disorder of varicose veins has association to other aliases such as chronic venous insufficiency (CVI), chronic venous disease (CVD) (Naoum & Hunter, 2007; VascularWeb, 2007), and even spider veins (telangiectasia) (Feied & Weiss, 2005). The objectives of the veins of the body are to perform as the return highway system back to the heart as well as act as the means to relieve cells of waste materials. The cause of varicose veins is due to the inability of the lower legs' superficial and deep veins to perform their functions properly. This means that the blood is being transported away from their normal venous pathway to tributary branches that are unable to handle this incoming volume (Feied & Weiss, 2005). When this occurs, the physiological changes result as enlarged veins (1 to 3 millimeters in diameter) for both the subdermal and intradermal layers of the leg's venous system (Naoum & Hunter, 2007). Aside from the aesthetic symptom of enlarged venous cavities, other symptoms of varicose veins noted can be discomfort or heaviness of legs, restlessness of legs, ulceration, bleeding, night cramping, peresthesia, fatigue, and tenderness along the vein when palpated (Feied & Weiss, 2005; Naoum & Hunter, 2007).

Risks for LE varicose veins have been studied from the perspectives of occupational risks as well as personal ones, with the latter being the more prevalent risks listed. The majority of occupational risks focus on repeated prolonged durations of standing (Barnes, 1995; Feied & Weiss, 2005; Kroeger, Ose, Rudofsky, Roesener, & Hirche, 2004; Laurikka et al., 2002; Naoum & Hunter, 2007; Stvrtinova et al., 1991; Tuchsen, Krause, Hannerz, Burr, & Kristensen, 2000; VascularWeb, 2007; Ziegler, Eckhardt, Stoger, Machula, & Rudiger, 2003) and in two references, extended sitting (Barnes, 1995; VascularWeb, 2007). Extensive standing as revealed by Feied and Weiss (2005), can affect the superficial venous system by decreasing venous capability and increasing venous wall expansion. Stvrtinova's et al. (1991) study showed the existence of significance of the association of varicose veins to standing ($p < 0.05$). Tuchsen's et al. (2000) varicose vein standing study in Denmark had significance values of risk ratios for both males and females (RR = 1.85, 95% CI: 1.33-2.36; RR = 2.63, 95% CI: 2.25-3.02, respectively).

There are several personal risk factors that exist. Gender wise, studies have suggested that women have shown a higher prevalence in varicose vein diagnoses than men (Feied & Weiss, 2005; Kroeger et al., 2004; Laurikka et al., 2002; Naoum & Hunter, 2007; VascularWeb, 2007; Ziegler et al., 2003). Pregnancy or past pregnancy are also personal risk factors for varicose veins (Barnes, 1995; Feied & Weiss, 2005; Fowkes et al., 2001; Laurikka et al., 2002; Naoum & Hunter, 2007; Stvrtinova et al., 1991; VascularWeb, 2007). Fowkes et al. (2001) found this association to have an odds ratio of 1.20 (95% CI: 0.93-1.54) for a Scottish study. In this same study, men who developed varicose veins were found to have a connection with height (OR = 1.13, 95% CI: 1.02-1.26) and bowel movement straining (OR = 1.94, 95% CI: 1.12-3.35). Other studies have concluded that aging is a factor for development due to loss of elasticity in the venous cavities' lamina (Barnes, 1995; Feied & Weiss, 2005; Naoum & Hunter, 2007; Stvrtinova et al., 1991; VascularWeb, 2007). Laurikka et al. (2002) noted in their Finland investigation that age had an odds ratio association with a range of 2.2-2.8. Numerous investigations found another major personal risk to be with heredity (Barnes, 1995; Feied & Weiss, 2005; Kroeger et al., 2004; Laurikka et al., 2002; Naoum & Hunter, 2007; Stvrtinova et al., 1991; VascularWeb, 2007). This is due to the genetic inheritance property gained from parents. An example may be if one or both parents may have been susceptible to vascular valve disorders which could create venous tributary bypasses that lead to varicose veins (Feied & Weiss, 2005). Kroeger et al. (2004) found this type of association to have an odds ratio of 5.2 (95% CI: 3.7-7.3) in their German study. A last personal risk numerously noted deals with obesity (Barnes, 1995; Laurikka et al., 2002; Naoum & Hunter, 2007; Stvrtinova et al., 1991; VascularWeb, 2007). Stvrtinova et al. (1991) noticed this association from their study of female department store workers ($p < 0.05$). Additional risks are listed in Table 2-12.

Table 2-12 Occupational and personal risk factors that may cause development of varicose veins

	Risk Factors											
Source	Heredity	Obesity	Prolonged Standing	Prolonged Sitting	Female Tendency	Older Age	Pregnancy	Race	Strained Bowel Movement	Height	Smoking	High Humidity and Temperature
(Barnes, 1995)	X	X	X	X		X	X	X	X			
(Feied & Weiss, 2005)			X		X	X	X					
(Fowkes et al., 2001)							X		X	X		
(Kroeger et al., 2004)	X		X		X	X						
(Laurikka et al., 2002)	X	X	X		X	X	X					
(Naoum & Hunter, 2007)	X	X	X	X	X	X	X					
(Tuchsen et al., 2000)			X									
(Stvrtinova et al., 1991)	X	X	X			X	X					
(VascularWeb, 2007)	X	X	X	X	X	X	X				X	
(Ziegler et al., 2003)			X		X							X

Joint System WMSDs

Joint systems WMSDs consisted of two forms of joint osteoarthritis (OA) for the hip and the knee. It also includes two other knee disorders (meniscal lesions and bursitis).

Hip

Hip Osteoarthritis

Hip osteoarthritis (OA) is known the be the most prevalent disorder for the hip joint (Hadler, 1993). Hadler (1993) further reveals that 2% of adults in the US will experience minor cases of OA by 80 years old and that another 2% from the same age group will feel the affects of even more severe OA cases. OA is a form of arthritis (joint inflammation) that involves the degenerative dissolution of normal cartilage behavior and function. Directly, OA causes cartilage to loose flexibility and become more firm. This loss in elasticity is a predisposition to destruction of the cartilage itself by allowing it to become damaged more easily during articulation and weight bearing activity. Breakdown of a joint's cartilage can not only cause a loss in shock absorption during weight bearing, but it can also allow ligament and tendon elongation and possibly bone to bone contact during joint movement, with the latter causing severe pain. Symptoms of OA in general, are joint inflammation and pain, as well as soreness during prolonged periods of usage or inactivity (WebMD,).

Hip OA, like other forms of joint OA, can be measured by severity level. These levels are defined by grades of 0 – 4. A grade of 0 means that there are no noticeable signs of degeneration. Grade 1 represents partial change in the joint with osteophytic lipping.

Grade 2 denotes definitive osteophytes with a potential for joint space narrowing. Grade 3 shows numerous signs of osteophytes with an obvious decrease in joint space along with sclerosis and irregularity in bone and cartilage endings. The highest severity level of 4 shows an evident narrowing of joint spacing along with extreme bone end damage and sclerosis (Kellgren & Lawrence, 1963).

Occupations affected with hip OA tend to noticed for blue collar labor where the work is known to be physically demanding. Examples of concerned industries include construction, food processing, fire fighting (Vingard et al., 1991; Vingard, Alfredsson, Goldie, & Hogstedt, 1991), postal industry (female mail carriers), mining (Vingard et al., 1991), and farming work (Thelin & Holmberg, 2007; Vingard et al., 1991; Vingard et al., 1991). Thelin and Holmberg (2007) in particular noted that farming had a hazard ratio (HR) of 3.0 (95% CI: 1.7,5.3).

Heavy manual labor has been associated to hip OA (OR = 6.7, 95% CI: 2.3,19.5) (Juhakoski et al., 2009). Juhakoski et al. (2009) explain this type of work involves prolonged standing with short episodes of sitting, lifting and carrying light to heavy objects, and exposures to vibrations (drilling, hammering, or excavating). They note that this type of work is found in the construction, manufacturing and farming environments. This study also found that an association existed for light to moderately heavy labor (OR = 3.1, 95% CI: 1.2,8.0). A description of this type of categorization includes moving continuously such as walking long distances, stooping, carrying objects of light weight, stair ascending and descending. Example job types vary from message deliver, to forest surveying, and light amounts of industrial labor.

If occupational risk factors are categorized according to the descriptors used by Juhakoski et al. (2009), then using vibration tools for more than an hour a day would be considered as one type of risk (female: OR = 7.9, 95% CI: 0.8,77.8) (Lau et al., 2000). A Swedish study noticed a link between the disorder and women who performed heavy lifting (Vingard, Alfredsson, & Malchau, 1997). Although, Vingard, Alfredsson, and Malchau (1997) did not include a specific weight threshold, they did include the number of lifts to be between 44,089 and 95,040 for women by the age of 50 years old (RR = 1.5, 95% CI: 0.9,2.5). Lau et al. (2000) also mentioned an association between hip OA and at least one hours' worth of digging activity for women (OR = 2.2, 95% CI: 0.8,6.5). Moderate to heavy lifting and carrying of objects weighing at least 22 pounds seems to also show a connection. Lau et al. (2000) found that lifting this weight association (or heavier) at least 10 times per week proved to be a risk for both men and women (male: OR = 3.1, 95% CI: 0.7.14.3; female: OR = 2.4, 95% CI: 1.1.5.3). Another study looked at occupationally related lifting in greater detail, dissecting object weights into three categories of 22 pounds or greater (OR = 1.2, 95% CI: 0.6,2.1), 55 pounds or greater (OR = 1.5, 95% CI: 0.7,3.0), and 110 pounds or greater (OR = 4.1, 95% CI: 1.1,15.2) (Yoshimura et al., 2000).

Standing and jumping between different levels were both reviewed in one study about women (Vingard et al., 1997). The authors found that by the age of 50 years old, women that were exposed to between 51,547-67,760 hours of standing (RR = 1.6, 95% CI: 0.9,2.8) and 9,241-55,924 jumps from different surface levels (RR = 2.1, 95% CI: 1.2,3.6) were coupled with the disorder. Additional work-related postures include at least one hour of exposure for squatting (OR = 1.3, 95% CI: 0.6,2.8) (Yoshimura et al., 2000) or kneeling (male: OR = 7.4, 95% CI: 0.7,76.9) (Lau et al., 2000). As mentioned in the description of light to moderately heavy labor (Juhakoski et al., 2009), stair climbing was defined to be a risk by Lau et al. (2000) when at least 15 flights of stairs are climbed per work day (male: OR = 12.5, 95% CI: 1.5,104.3; female: OR = 2.3, 95% CI: 0.6,8.1). Driving for at least four hours per day was also found to be associated to hip OA according to Yoshimura et al. (2000).

The most common personal risk factor noted by studies to be associated to hip OA is past injury to the hip (Cooper et al., 1998; Heliovaara et al., 1993; Juhakoski et al., 2009). Odds ratios for each of the studies were at 4.3 (95%CI: 2.2,8.4), 1.9 (95%CI: 1.4,2.6), and 5.0 (95%CI: 1.9,13.3), respectively. Additionally, Lau et al. (2000) separated this relationship (between risk factor and disorder) for each gender (male: OR = 25.1, 95% CI: 3.5,181; female: OR = 43.3, 95% CI: 11.7,161). Following injury history, body mass index (BMI) was also listed by studies to be a risk factor (Cooper et al., 1998; Heliovaara et al., 1993). BMI is one indicator used to measure human body weight and its proportion of body fat. A BMI score of less than 20 is known as underweight; a score of 20-25 is considered as normal weight; a score between 25 and less than 30 is overweight; obese is considered a BMI greater than 30 and less than or equal to 35; and very obese is that greater than 35 (J. J. Anderson & Felson, 1988). Cooper et al. (1998) recorded associated

BMI scores at 28 or greater (OR = 1.9, 95% CI: 1.4,2.8). Heliovaara et al. (1993) found that the association exists in further detail, being broken into BMI scores for 25-29.9 (overweight) (OR = 1.5, 95% CI: 1.1,1.9), 30-34.9 (obese) (OR = 2.0, 95% CI: 1.5,2.7), and >35 (very obese) (OR = 2.0, 95% CI: 1.1,3.5).

Further studies found that athletic activity could also pose a risk (Cooper et al., 1998; Kujala, Kaprio, & Sarna, 1994; Lau et al., 2000). Kujala, Kaprio, and Sarna (1994) looked at this association from the perspective of professional athletics and relationships with hip, knee, and ankle OA later on in life. Endurance athletes such as distance running were found to develop OA later on in life (OR = 1.73, 95% CI: 0.99,3.01) versus mixed sport (OR = 1.90, 95% CI: 1.24,2.92) or power sport (OR = 2.17, 95% CI: 1.41,3.32) athletes. Cooper et al. (1998) narrowed the athletic activities to tennis (OR = 1.6, 95% CI: 1.1,2.2), swimming (OR = 1.5, 95% CI: 1.1.2.0), and golf (OR = 1.5, 95% CI: 0.8,2.9) whereas Lau et al. (2000) noticed gymnastics among women (OR = 1.9, 95% CI: 0.3,11.1). Other risks include a diagnosis of Herberden's nodes (OR = 1.5, 95% CI: 1.2,2.2) (Cooper et al., 1998) and increasing in age (Riihimaki, 1995).

Knee

Knee disorders are the most common joint disorder for the LE. In their study of knee disorders affecting Britain's Hampshire communities, Baker et al. (2003) noticed that 14% of the population surveyed had a median number of lost days from work of 14. Additionally, they also mention that 1% of those surveyed had to leave their job due to their knee problem. From the literature, it is revealed that the majority of the knee disorders that result from kneeling inclined occupations are knee osteoarthritis, meniscal (meniscus) disorders, and knee bursitis (Baker, Reading, Cooper, & Coggon, 2003; Kivimaki, Riihimaki, & Hanninen, 1994).

Knee Osteoarthritis

Confirmation of knee OA and its stages of development can be diagnosed using the same methods from hip OA; x-ray radiographs or MRIs. During the diagnosis process, a search is done for signs of worn cartilage, narrowed joint spaces, osteophytes, meniscus damage, and/or bony sclerosis and cysts (Felson, 2006).

A multitude of occupations have been affected by knee OA. The listing of occupations includes miners, firemen, construction workers, taxi drivers, beverage delivery workers and many more (Table 2-13). The high quantity of jobs that are affected may be due to the commonness of the postural activities that are utilized by them. Postures noted by literature frequently refer to knee flexion and bending postures and activities such as kneeling (Coggon et al., 2000; Cooper, McAlindon, Coggon, Egger, & Dieppe, 1994; Jensen, Mikkelsen, Loft, & Eenberg, 2000; Kivimaki, Riihimaki, & Hanninen, 1992), squatting (Coggon et al., 2000; Cooper et al., 1994; Jensen, Mikkelsen, Loft, & Eenberg, 2000), and stair/ladder climbing (Lau et al., 2000). Additionally, Lau et al. (2000) mentions that vibration exposure from tools can also be considered as an occupational risk. Coggon et al. mention that in their study the activity of walking was also noted to show a relationship to knee OA (OR = 1.9, 95% CI: 1.4,2.8) (Coggon et al., 2000).

It should be noted that the risk factor stair/ladder climbing is based on the number of flights climbed per 8 hour day. With that, the number of steps per flight may be questioned. Stair case design is dependent on the type of building structure it is constructed in. The total rise of a stair flight between floors can vary between 8 feet (for homes) and 10 feet (for businesses). This height creates an angle of incline that according to OSHA standard 29 CFR 1910.24(e) should be between 30 and 50 degrees (Occupational Safety & Health Administration,). A more ideal range between 30 and 35 degrees has also been suggested (Brauer, 2006). The Life Safety Codes recommend that the rise and run of a stair step be no more than 7 and 11 inches, respectively (National Fire Protection Association, 2006). With this information, a rise angle of 30° was chosen whose rise and run (tread depth) were equivalent to 6.5 and 11 inches. Calculating these constraints reveals that for flight rises of 8 and 10 feet, the number of stairs will be 15 and 18, respectively. This produces a mean of 16.5 steps per stair flight. The study performed by Coggon et al. (2000) was the only study found to have an association for stair/ladder climbing as a risk factor for knee OA. However, they did not expand on the definition for the number of steps in a stair/ladder flight.

Several authors have noticed an association between physical workload (such as lifting and carrying) and knee OA (Coggon et al., 2000; Felson et al., 1991; Lau et al., 2000; Manninen, Heliovaara, Riihimaki, & Suomalainen, 2002; Sandmark, Hogstedt, & Vingard, 2000). Physical workload has been defined in several quantities but a standard of 5 levels have been used by the US government to denote exposure levels (US Department of Labor, 1977). The levels noted are sedentary, light, medium, heavy, and very heavy. Sedentary refers to handling only a maximum of 10 pounds with little walking or standing. Light physical workload has a maximum handling of 20 pounds with recurrent carrying of up to 10 pounds. Medium has a maximum of 50 pounds with 25 pounds of frequent carrying. Heavy physical workload has a 100 pound maximum with 50 pounds of recurring carrying. The last category of very heavy has a maximum lift that exceeds 100 pounds and frequent carries of greater than 50 pounds. Interestingly enough, studies have noticed that a combinational affect occurs when a physical workload is performed during knee bending postures and activities (Coggon et al., 2000; Cooper et al., 1994; Felson et al., 1991; Lau et al., 2000; Manninen et al., 2002; Sandmark et al., 2000). A few of these have even quantified this combinational affect to an extent, mentioning mainly that lifting and carrying items that weigh 25 to 55 pounds whilst kneeling, squatting, stair/ladder climbing, crouching, or crawling, can amplify possible knee OA progression (Table 2-14) (Coggon et al., 2000; Cooper et al., 1994; Felson et al., 1991).

Occupational risks do make up the majority of possible causes to knee OA but, there are also several personal risk factors that are related to an individual's life history (Table 2-15). For example, it is well-known that past knee problems such as meniscal disorders or even surgeries such as menisectomies can increase the likelihood that OA may develop later on in life (Cooper et al., 1994; Felson et al., 1991; Lau et al., 2000; Manninen et al., 2002; McMillan & Nichols, 2005; Wickstrom et al., 1983). Lau et al. (2000) reveal this connection to exist in both male and female genders (male: OR = 12.1, 95% CI: 3.4,42.5; female: OR = 7.6, 95% CI: 3.8,15.2). Cooper et al. (1994) view the combinational risk of past injury with kneeling, squatting, or stair climbing as a greater risk for this degenerative disorder (OR = 7.6, 95% CI: 2.1,26.9).

Obesity is another variable mentioned to be a factor in the development of knee OA (J. J. Anderson & Felson, 1988; Coggon et al., 2000; Cooper et al., 1994; Felson et al., 1991; Lau et al., 2000). Cooper et al. (1994) note that the threshold of risk begins with a BMI score of 25.3 (OR = 3.6, 95% CI: 1.7,7.5). Anderson and Felson (1988) point out that BMI scores indicating obese or greater are at risk for development of knee OA (male: OR = 4.78, 95% CI: 2.77,8.27; female: OR = 3.87, 95% CI: 2.63,5.68). Moreover, is the increased risk mentioned by Coggon et al. (2000) when high BMI is merged with kneeling and squatting postures (Table 2-16). Overweight workers are already considered by their study to be at risk (OR = 6.1, 95% CI: 3.4,10.9), whereas obesity and above increases the connection (OR = 14.7, 95% CI: 7.2,30.2).

Lastly, some studies add that an aging workforce may also be a contributing personal factor in industry (J. J. Anderson & Felson, 1988; Felson et al., 1991). Although Anderson and Felson (1988) noticed that women in the age group of 45-54 were initially susceptible (OR = 2.07, 95% CI: 0.71,6.08), the authors particularly talk about those workers noted to be in the age group of 55-64 years old and higher having a greater inclination towards knee OA development for both gender groups when combined with knee bending postural activities such as kneeling, squatting, or stair climbing (male: OR = 2.45, 95% CI: 1.21,4.97; female: OR = 3.49, 95% CI: 1.22,10.52).

Table 2-13 Occupations affected by knee osteoarthritis

Occupation	Source
Firefighter	Vingard et al., 1991
Farm Worker	Sandmark et al., 2000; Vingard et al., 1991
Construction Worker	Sandmark et al., 2000; Vingard et al., 1991
Fishing Workers	Lau et al., 2000
Civil Servants	Partridge & Duthie, 1968
Dock Worker	Partridge & Duthie, 1968
Carpet/Floor Layer	Jensen et al., 2000; Jensen, Mikkelsen, Loft, & Eenberg, 2000; Kivimaki et al., 1994
Tilesetter	Thun et al., 1987
Forestry Worker	Sandmark et al., 2000
Carpenter	Jensen et al., 2000; Jensen, Mikkelsen, Loft, & Eenberg, 2000
Cleaning Workers (female)	Rossignol et al., 2005; Vingard et al., 1991
Miner	Atkins, 1957; McMillan & Nichols, 2005
Millwrights & Bricklayers	Thun et al., 1987

Personally attributable confounders such as habits and hobbies are also known to exist for knee OA risks. Lau et al. (2000) state that in their study they found athletic hobbies such as gymnastics and kung fu to be associated to knee OA in Hong Kong Chinese women. High load bearing and repetition were seen by the authors as the culprits of blame for these associations. These same hobbies were not found to be significant in men, however.

Table 2-14 Occupational risk factors and knee osteoarthritis guideline

Occupational Risk Type	Posture or Activity	Exposure Quantity	Statistical Measure	Source
Posture	Squatting	> 30 mins / work day	(OR = 6.9, 95% CI: 1.8,26.4)	Cooper et al., 1994
	Squatting	> 1 hr / work day	(OR = 2.3, 95% CI: 1.3,4.1)	Coggon et al., 2000
	Kneeling	> 30 mins / work day	(OR = 3.4, 95% CI: 1.3,9.1)	Cooper et al., 1994
	Kneeling	> 1 hr / work day	(OR = 1.8, 95% CI: 1.2,2.6)	Coggon et al., 2000
	Kneeling or squatting	> 2 hr / work day	(OR = 1.73, 95% CI: 1.13,2.66)	Manninen et al., 2002
Activity	Stair climbing	> 10 flights / work day	(OR = 2.7, 95% CI: 1.2,6.1)	Cooper et al., 1994
	Stair climbing (men)	≥ 15 flights / work day	(OR = 2.5, 95% CI: 1.0,6.4)	Lau et al., 2000
	Stair climbing (women)	≥ 15 flights / work day	(OR = 5.1, 95% CI: 2.5,10.2)	Lau et al., 2000
	Stair/Ladder climbing	> 30 flights / work day	(OR = 1.5, 95% CI: 1.0,2.3)	Coggon et al., 2000
	Lifting ≥ 22 lbs (men)	≥ 10 times / work week	(OR = 5.4, 95% CI: 2.4,12.4)	Lau et al., 2000
	Lifting ≥ 22 lbs (women)	≥ 10 times / work week	(OR = 2.0, 95% CI: 1.2,3.1)	Lau et al., 2000
	Lifting ≥ 55 lbs	> 10 times / work week	(OR = 1.7, 95% CI: 1.2,2.6)	Coggon et al., 2000
	Lifting ≥ 110 lbs	> 10 times / work week	(OR = 1.4, 95% CI: 0.9,2.2)	Coggon et al., 2000
	Lifting/carrying (women)	≥ 25-50 lbs / item	(OR = 2.53, 95% CI: 0.82,7.85)	Felson et al., 1991
	Heavy lifting combined with kneeling, squatting, or stair climbing	> 55 lbs / item	(OR = 5.4, 95% CI: 1.4,21.0)	Cooper et al., 1994
	Lifting/carrying combined with kneeling, squatting, crouching or crawling (men)	≥ 25-50 lbs / item	(OR = 2.22, 95% CI: 1.38,3.58)	Felson et al., 1991
	Heavy lifting combined with kneeling or squatting	> 55 lbs / item	(OR = 3.0, 95% CI: 1.7,5.4)	Coggon et al., 2000
	Walking	> 2 miles / work day	(OR = 1.9, 95% CI: 1.4,2.8)	Coggon et al., 2000
Tool Usage	Vibration tools (men)	≥ 1 hr / work day	(OR = 2.8, 95% CI: 0.8,10.0)	Lau et al., 2000
	Vibration tools (women)	≥ 1 hr / work day	(OR = 3.7, 95% CI: 0.7,20.1)	Lau et al., 2000

OR = Odds Ratio; CI = Confidence Interval

Table 2-15 Personal risks and knee OA

Personal Risk Type	Personal Risk	Statistical Measure	Source
Injury History	Past injury or surgery (men)	(OR = 12.1, 95% CI: 3.4,42.5)	Lau et al., 2000
	Past injury or surgery (women)	(OR = 7.6, 95% CI: 3.8,15.2)	Lau et al., 2000
Body Mass Index (Overweight)	BMI > 25.3	(OR = 3.6, 95% CI: 1.7,7.5)	Cooper et al., 1994
	BMI 25 – 29.9 (men)	(OR = 1.69, 95% CI: 1.03,2.80)	Anderson & Felson, 1988
	BMI 25 – 29.9 (women)	(OR = 1.89, 95% CI: 1.24,2.87)	Anderson & Felson, 1988
Body Mass Index (Obese)	BMI 30 - 35 (men)	(OR = 4.78, 95% CI: 2.77,8.27)	Anderson & Felson, 1988
	BMI 30 - 35 (women)	(OR = 3.87, 95% CI: 2.63,5.68)	Anderson & Felson, 1988
Body Mass Index (Very Obese)	BMI > 35 (men)	(OR = 4.45, 95% CI: 1.77,11.18)	Anderson & Felson, 1988
	BMI > 35 (women)	(OR = 7.37, 95% CI: 5.15,10.53)	Anderson & Felson, 1988

OR = Odds Ratio; CI = Confidence Interval

Table 2-16 Combinational risk of kneeling/squatting/stair climbing with age, injury history, or BMI scores for knee OA

Personal Risk Type	Personal Risk	Statistical Measure	Source
Age	Age 45-54 (women)	(OR = 2.07, 95% CI: 0.71,6.08)	Anderson & Felson, 1988
	Age ≥ 55-64 (men)	(OR = 2.45, 95% CI: 1.21,4.97)	Anderson & Felson, 1988
	Age ≥ 55-64 (women)	(OR = 3.49, 95% CI: 1.22,10.52)	Anderson & Felson, 1988
Injury History	Past Injury or surgery	(OR = 7.6, 95% CI: 2.1,26.9)	Cooper et al., 1994
Body Mass Index (Normal weight)	BMI < 25	(OR = 2.2, 95% CI: 1.1,4.5)	Coggon et al., 2000
Body Mass Index (Overweight)	BMI 25 – 29.9	(OR = 6.1, 95% CI: 3.4,10.9)	Coggon et al., 2000
Body Mass Index (Obese)	BMI ≥ 30	(OR = 14.7, 95% CI: 7.2,30.2)	Coggon et al., 2000

OR = Odds Ratio; CI = Confidence Interval

Meniscal Disorders

A cumulative meniscal lesion or tear can occur when a portion of either the medial or lateral meniscus' cartilage is consistently caught in between the condyles of the femur and tibia during knee flexion which may slowly erode the material over time (Sharrard & Liddell, 1962). Sharrard and Liddell (1962) propose another theory of meniscal damage by revealing that a predisposing cumulative laxity of the knee from kneeling may be a determinant that could lead to a sudden acute menisci tear. The area primarily accused is that of the anterior cruciate ligament (ACL) where it is noted that sudden jerking movements or extreme internal/external leg rotations (twisting) can lead to it stretching (or slowly tearing) over time while in a kneeling posture (Atkins, 1957; Sharrard & Liddell, 1962). Sharrard and Liddell (1962) and Sharrard (1964) disclose that the actual resulting evidence of meniscal damage may or may not occur while kneeling and can possibly happen while also walking, standing, stooping, or crawling. They infer that this may happen due to the knee's newfound laxity and instability. Sharrard (1964) adds that this sudden damage is due to a rapid movement (instead of static postures) such as a stagger or avoidance of a hazard in combination with the laxity that may cause abrupt meniscus lesions. Symptoms of the onset of meniscal disorders are perceived as pain, stiffness, knee locking, swelling, laxity, and grating, with the first two symptoms being the most commonly stated (Baker et al., 2003)

Meniscal lesions or tears are injuries commonly reported in athletic events such as soccer or rugby (Atkins, 1957; Baker et al., 2002; Baker et al., 2003). Additional risk association was found by Baker et al. (2002, 2003) in running and swimming activities. Details of these athletic risks are given in Baker's et al. (2003) study and are noted to be seen as possible confounders in men that participate in these activities (soccer: OR = 6.9, 95% CI: 3.5,13.3; rugby: OR = 3.4, 95% CI: 1.5,7.8; running: OR = 1.4, 95% CI: 0.5,3.7; swimming: OR = 1.6, 95% CI: 0.8,3.0).

There are considerably few studies that review the nature of occurrence of meniscal disorders and of these, the occupations mentioned seem to continuously reference the mining and floor (or carpet) laying industries (Atkins, 1957; Jensen & Eenberg, 1996; Kivimaki, 1992; McMillan & Nichols, 2005; Sharrard & Liddell, 1962). It can be safe to assume though that other industries can also be susceptible where knee bending postures and activities are heavily utilized. Of the studies reviewed for this disorder, only two (Baker et al., 2002, 2003) provided statistical measures for risk factors. Risk factors that are mentioned are kneeling, squatting, stair climbing, standing, sitting while driving, walking, and lifting and carrying heavy objects (Table 2-17). Moreover, both studies also add that the act of getting up from a kneeling or squatting position can add strain to the knee that could possibly lead to meniscal damage. Baker et al. (2003) propose a risk association when this act is performed more than 30 times per work day (OR = 1.9, 95% CI: 1.0, 3.8). Personal risk factors referred only to the sporting and hobby activities that were previously mentioned for this disorder.

Table 2-17 Occupational risk factors and meniscal disorders guideline

Occupational Risk Type	Posture or Activity	Exposure Quantity	Statistical Measure	Source
Posture	Squatting	> 1 hr / work day	(OR = 1.8, 95% CI: 1.1,3.0)	Baker et al., 2002
	Squatting (men)	> 1 hr / work day	(OR = 2.5, 95% CI: 1.2,4.9)	Baker et al., 2003
	Kneeling	> 1 hr / work day	(OR = 2.2, 95% CI: 1.3,3.6)	Baker et al., 2002
	Kneeling (men)	> 1 hr / work day	(OR = 2.5, 95% CI: 1.3,4.8)	Baker et al., 2003
	Chair sitting (while driving)	> 4 hrs / work day	(OR = 2.3, 95% CI: 1.4,4.0)	Baker et al., 2002
Activity	Standing up from kneel or squat position	> 30 times / work day	(OR = 1.9, 95% CI: 1.2,3.1)	Baker et al., 2002
	Standing up from kneel or squat position (men)	> 30 times / work day	(OR = 1.9, 95% CI: 1.0,3.8)	Baker et al., 2003
	Stair climbing	> 30 flights / work day	(OR = 2.4, 95% CI: 1.6,3.8)	Baker et al., 2002
	Stair climbing (men)	> 30 flights / work day	(OR = 2.0, 95% CI: 1.0,4.1)	Baker et al., 2003
	Standing (men)	> 2 hrs / work day	(OR = 1.5, 95% CI: 0.8,3.1)	Baker et al., 2003
	Walking	> 2 miles / work day	(OR = 1.5, 95% CI: 0.9,2.3)	Baker et al., 2002
	Walking (men)	> 2 hrs / work day	(OR = 1.5, 95% CI: 0.8,3.1)	Baker et al., 2003
	Lifting or moving heavy items (men)	> 22 lbs / item	(OR = 1.7, 95% CI: 0.9,3.1)	Baker et al., 2003
	Lifting items ≥ 22 lbs	> 10 times / work week	(OR = 1.9, 95% CI: 1.2,2.9)	Baker et al., 2002
	Lifting items ≥ 55 lbs	> 10 times / work week	(OR = 1.7, 95% CI: 1.1,2.7)	Baker et al., 2002
	Lifting items ≥ 110 lbs	> 10 times / work week	(OR = 2.4, 95% CI: 1.4,4.2)	Baker et al., 2002

OR = Odds Ratio; CI = Confidence Interval

Knee Bursitis

Bursitis is the irritation and inflammation of a bursa sac and can be diagnosed as either acute or chronic. For the knee joint, the two most commonly affected bursas are the prepatellar bursa (along the anterior portion of the patella bone) followed by the superficial infrapatellar bursa (along the anterior-superior portion of the tibia bone of the knee joint) (Myllymaki, Tikkakoski, Typpo, Kivimaki, & Suramo, 1993). Pseudonyms of knee bursitis are known as “beat knee” from the coal mining industry (Myllymaki et al., 1993; Sharrard, 1964; Thun et al., 1987; Watkins, Hunt, Fernandez, & Edmonds, 1958), “carpet-layer’s knee” from carpet and floor laying (Myllymaki et al., 1993; Thun et al., 1987) and “housemaid’s knee” (Thun et al., 1987). Myllymaki et al. (1993) describe symptoms of knee bursitis to include redness and tenderness, and swelling of the affected knee bursa area in the prepatellar region. Detection tools of bursitis in general, include radiographs, magnetic resonance images (MRI), and ultrasounds, with the latter being more accurate than radiographs and faster and less costly than MRIs. Diagnosis of bursitis by ultrasound includes detection of oval-like hypoechoic structures accompanied by fluid aggregation and possible bursa thickening.

Knee bursitis has been noted in the literature to occur in a multitude of occupations. Typically the disorder is associated to jobs that entail protracted knee straining work such as kneeling and squatting (Jensen, Mikkelsen, Loft, & Eenberg, 2000). Occupations notorious for extended kneeling postures are coal mining (Myllymaki et al., 1993; Sharrard, 1964; Thun et al., 1987; Watkins et al., 1958) and carpet (floor) laying (Bhattacharya, Mueller, & Putz-Anderson, 1985; Jensen, Mikkelsen, Loft, & Eenberg, 2000; Kivimaki, 1992; Myllymaki et al., 1993; Thun et al., 1987). Kivimaki et al. (1992) noticed in their study that 19% of their carpet layers developed prepatellar bursitis. In Jensen’s et al (2000) study, the two investigating physicians diagnosed 10% and 8% of the carpet laying workers with knee bursitis. 20% of Thun’s et al. (1987) carpet laying participants were diagnosed with knee bursitis during the study. In Watkins' et al. (1958) study of beat knee in coal mining, the mean lost work shifts was 5.7 and 10% of the 899 participants had recurring episodes of knee bursitis. Additional occupations aside from the mining and floor laying industries include house cleaning (Myllymaki et al., 1993; Thun et al., 1987) tile setting (Thun et al., 1987), and manufacturing (Bruchal, 1995), as well as the sport of wrestling (Myllymaki et al., 1993). Fishermen at sea also are known to develop prepatellar bursitis due to the pressure exerted on the prepatellar knee region by the boat's equipment and surfaces (Torner, Almstrom, Karlsson, & Kadefors, 1994). The authors mention that the knee disorder actually develops during standing while the workers are performing their tasks and need to stabilize themselves with the front of their legs and knees during the boat's rocking movements.

As previously stated, kneeling is the primary occupational risk variable associated with the development of prepatellar and superficial infrapatellar bursitis. Thun's et al. (1987) study showed that when compared to tilesetters, millwrights, and bricklayers, carpet layers were revealed to have a higher prevalence towards developing knee bursitis (Prevalence Ratio = 3.2). The authors propose that this is likely due to the high repetition and duration of kneeling within their occupation. Sharrard's (1964) review of coal mining implies that due to the dynamically fluctuating pressures that the prepatellar regions of the knees are exposed to while kneeling and working, it is of no surprise that blood vessels would eventually rupture in the prepatellar bursa and produce the swelling and haemobursa noticed in acute prepatellar bursitis. Few knee pads of the day did provide reasonable protection to the prepatellar bursa against this alternating knee pressure.

Although 91% of Watkins' et al. (1958) surveyed participants did wear knee pads daily while working, prepatellar bursitis still occurred. A concurrence with this premise is mentioned by Sharrard (1964) who reveals that prepatellar bursitis occurred twice as frequently as did its superficial infrapatellar counterpart with from the use of the knee pads. Watkins et al. (1958) point out that even though the knee's contact area with the work surface (while kneeling) focuses on the tibial tuberosity (below the patella), they feel that knee pads themselves may be redistributing the body weight's pressure back onto the prepatellar region. Some of the studies also noticed a connection between restricted work environments and recurrent usage of kneeling related postures due to this confinement (Sharrard, 1964; Watkins et al., 1958).

Use of a knee kicker is another occupational hazard that solely transpires in the carpet laying industry. The device is used to stretch carpet snuggly to a wall during installation (Thun et al., 1987). During this activity, while in a crawl position one of the knees is used a hammer against the tool while the other holds a portion of the body's weight (some is transferred into the arms as well). Thun et al. (1987) reveals that it is the suprapatellar region of the knee that provides the contact stress against the tool. An assessment done by Bhattacharya et al. (1985) discovered that the least forceful knee kicks against the tool provided 2469 N of force whereas a more excessive one could hit as high as 3019 N (approximately four times participant's body weight). A link was found by Thun et al. (1987) between use of a knee kicker and the development of knee bursitis (OR = 5.3, 90% CI: 2.8, 10.3).

Ankle

Posterior Tibial Nerve Entrapment (Tarsal Tunnel Syndrome)

Although established in the athletic and military industries, posterior tibial nerve entrapment (tarsal tunnel syndrome) is still considered an uncertain disorder topic for the ergonomics and occupational health communities and is still under debate. Although it does occur in the occupational environments, the personal and occupational variables involved and the relationships between them can be too indiscrete to establish consistently and reliably (Hollis et al., 2005). Tarsal tunnel syndrome is considered the ankle's equivalent to the wrist's carpal tunnel syndrome (Hadler, 1993). It is typically described as the entrapment or compression of the posterior tibial nerve or a branch stemming from it as it curves around the back of the ankle anteriorly towards the plantar foot region (Hollis et al., 2005). These entrapments can occur either in the foot or ankle regions. Hadler (1993) and Hollis et al. (2005) mention that the symptoms of tarsal tunnel vary subjectively and that diagnosing can be difficult to ascertain. One posture that was recognized was from Feldman et al. (1983) and involved leaning back in a chair while using plantar flexion to push. The authors state that this posture can cause compression on the posterior tibial nerve that runs behind the ankle.

Koch's Postulates (Table 2-18) is one method that is used to prove epidemics for people who may be susceptible to the disorder at hand (Guyton, Mann, Kreiger, Mendel, & Kahan, 2000). Guyton et al. (2000) were unable to prove the disorder as an epidemic due to it not fulfilling Koch's Postulates. Koch's Postulates is on tool used to prove that an epidemic or disorder needs to be addressed as prevalent for a particular population. So even though cases may occur in occupational environments outside dance and athletics, the authors argue that it is difficult to identify and duplicate the major occupational risk variable(s) that may contribute to the disorder.

Table 2-18 Koch's Postulates (Guyton et al., 2000)

Postulate Number	Explanation
1st Postulate	An increased occurrence of the disorder in an occupational environment
2nd Postulate	The associated population's mechanical stresses can be isolated
3rd Postulate	New previously unaffected workers to the occupational environment have shown symptoms of the disorder (prospective study)

Summary

The risks discussed in this section affect industrial occupations in one way or another. LE WMSDs noticed have the tendency to develop into sprain, strain, inflammation, pressure, nerve impairment, reduced blood flow, and vasospasms (Kroemer et al., 2001). In addition to these, soft tissue damage and disorders may have symptoms of soreness, bursitis, and in rare incidents outside of military and athletic occupations, bone stress fractures (Bureau of Labor Statistics, 2006b; Laker & Sullivan, 2006). Details of WMSDs noticed throughout the work of this review are summarized in Table 2-24 to include the occupations affected.

Much of the muscular and skeletal disorders reviewed appear in the athletic and military industries. Very few published examples have happened in occupations aside from these. Their disorders are still listed in this document due to the fact that their postures are known to occur in normal industries where intensity may not be as high but postural activities are similar. As with all of these disorders, cumulative exposure to an occupational risk is the cause that can lead to an effect. Future studies should target additional industries where there may be high probability in these risks taking place. The following Tables 2-19 – 2-20 lists references that associate to the disorders of the muscular and skeletal system accordingly.

Table 2-19 References and associated muscular WMSDs

	Muscular System Entrapment WMSD	
Source	Iliotibial Band Syndrome	Plantar Fasciitis
Adkins & Figler, 2000	X	
Barrett & O'Malley, 1999		X
Biundo et al., 2001	X	
Huang et al., 2000		X
Hurwitz, 2004		X
Kelly & Winston, 1994	X	
Martinez & Honsik, 2006	X	
Nishimura et al., 1997	X	
Riddle et al., 2003		X
Singh, 2006		X
Young et al., 2001		X

Table 2-20 References associated with stress fractures of the skeletal system

Stress Fracture Source
Bennell et al., 1996
Cowan et al., 1996
Donovan & Black, 1986
Giladi et al., 1985
Jones et al., 2002
Jordaan & Schwellnus, 1994
Laker & Sullivan, 2006
Rauh et al., 2006
Simkin et al., 1989
Warden et al., 2006

Association of neuropathy to risk is the first step in developing an epidemiological study. These were the types of investigations conducted by researchers in this review (Table 2-21). The next step would be the development of quantification such as an approximation in how much time to symptom development due to exposure. This will aid in the development of an initial set of guidelines that can be expanded at a later time into additional tools and models. So to that end, further epidemiological prospective and retrospective studies need to be conducted to reduce the occurrence of these disorders in working environments.

Table 2-21 References and their associated LE neuropathies

	Nerve Entrapment WMSD Region				
Source	Lateral Femoral Cutaneous Nerve	Common Peroneal Nerve	Superficial Peroneal Nerve	Deep Peroneal Nerve	Digital Nerves
Borges et al., 1981				X	
Fargo & Konitzer, 2007	X				
Feldman et al., 1983	X	X			X
Garland & Moorhouse, 1952		X			
Hadler, 1993	X	X			
Hollis et al., 2005	X	X	X	X	
Kaminsky, 1947		X			
Katirji & Wilbourn, 1988		X			
Kho et al., 2005	X				
Koller & Blank, 1980		X			
Kornbluth & Marone, 2006	X				
Mulder et al., 1961		X			
Nagler & Rangell, 1947		X			
Sekul, 2007	X				
Seppalainen et al., 1977		X			
Spaans, 1970		X			

Ischemia, vibration syndrome, and varicose veins have been empirically noted to being developed both traumatically and chronically. They were listed in this review due to the latter and also due to the fact that many occupations involve the occupational risks that have been listed such as prolonged standing or sitting. As in the previous section on nervous system WMSDs, the studies listed here are retrospective in their viewpoint. Prospective studies, although difficult to develop (due to the numerous personal risk variables), should be completed so that quantification values such as time of exposure can be aggregated. This will aid in the development of work procedures and plans for employers to be aware of as a set of guidelines. Table 2-22 shows the references that are involved in this review section's appraisal.

Table 2-22 References associated with vascular system WMSDs

	Vascular System WMSD		
Source	Ischemia	Vibration Syndrome	Varicose Veins
Barnes, 1995			X
Feied & Weiss, 2005			X
Feldman et al., 1983	X		
Fowkes et al., 2001			X
Hashiguchi et al., 1990		X	
Hashiguchi et al., 1994		X	
Kroeger et al., 2004			X
Laurikka et al., 2002			X
Matoba et al., 1985		X	
Naoum & Hunter, 2007			X
Sakakibara et al., 1991		X	
Sakakibara, 1994		X	
Sakakibara & Yamada, 1995		X	
Stvrtinova et al., 1991			X
Tingsgard & Rasmussen, 1994		X	
Thomas, 1993	X		
Toibana et al., 1994		X	
Tuchsen et al., 2000			X
VascularWeb, 2007			X
Ziegler et al., 2003			X

Joint disorders are the most popular noticed in this literature review due to the large quantity of referable material. They also seem to be the most studied as they have had many retrospective epidemiological population studies looking at the physiological "cause and effect" relationships (especially hip and knee osteoarthritis). These studies have also revealed many quantifiable relationships that go beyond having just an association. These hypothetical relationships have been summarized in tables that can be used as generic risk guidelines for occupations that may be susceptible to the listed postural activities. Due to this, they are likely to be a good starting point for the building of a LE risk model. Sources of joint system disorders are listed in Table 2-23.

Table 2-23 References associated with joint system WMSDs

	Joint System WMSD				
Source	Ankle- Tarsal Tunnel Syndrome	Knee Osteoarthritis	Knee Meniscal Disorder	Knee Bursitis	Hip Osteoarthritis (NA)
J. J. Anderson & Felson, 1988		X			
Atkins, 1957			X		
Baker et al., 2003			X		
Bhattacharya et al., 1985				X	
Coggon et al., 2000		X			
Cooper et al., 1994		X			
Cooper et al., 1998					X
Feldman et al., 1983	X				
Felson, 2006		X			
Guyton et al., 2000	X				
Hadler, 1993	X				
Heliovaara et al., 1993					X
Hollis et al., 2005	X				
Jensen & Eenberg, 1996			X		
Jensen, Mikkelsen, Loft, & Eenberg, 2000		X		X	
Jensen et al., 2000		X			
Juhakoski et al., 2009					X
Kellgren & Lawrence, 1963		X			
Kivimaki, 1992			X	X	
Kivimaki et al., 1992		X			
Kivimaki et al., 1994		X			
Lau et al., 2000		X			X
Manninen et al., 2002		X			
McMillan & Nichols, 2005		X	X		
Myllymaki et al., 1993				X	
Riihimaki, 1995					X
Sandmark et al., 2000		X			
Sharrard & Liddell, 1962			X		
Sharrard, 1964			X	X	
Thelin & Holmberg, 2007					
Thun et al., 1987				X	
Torner et al., 1994				X	
Vingard, Alfredsson, & Malchau, 1997					X
Watkins et al., 1958				X	
WebMD, NA		X			
Wickstrom et al., 1983		X			
Yoshimura et al., 2000					X

Table 2-24 An association table of WMSDs, occupations, and the musculoskeletal systems they affect

	Musculoskeletal System Affected				
Occupation	**Muscular System**	**Skeletal System**	**Nervous System**	**Vascular System**	**Joint System**
Police			Thigh- Lateral Femoral Cutaneous Neuropathy		
Military	Thigh- Iliotibial Band Syndrome, Stress Fracture, Lower Leg- Stress Fracture, Foot- Stress Fracture	Thigh- Stress Fracture, Lower Leg- Stress Fracture, Foot- Stress Fracture	Thigh- Lateral Femoral Cutaneous Neuropathy		
Carpentry			Thigh- Lateral Femoral Cutaneous Neuropathy		
Agricultural Worker			Lower Leg- Common Peroneal Neuropathy		Hip- Osteoarthritis
Mining			Lower Leg- Common Peroneal Neuropathy		Hip- Osteoarthritis, Knee- Knee Bursitis, Meniscal Disorders, Osteoarthritis
Shoe Sales			Lower Leg- Common Peroneal Neuropathy		
Athlete	Thigh- Iliotibial Band Syndrome, Stress Fracture, Lower Leg- Stress Fracture, Foot- Stress Fracture		Lower Leg- Common Peroneal Neuropathy		
Department Store Worker				Lower Leg- Varicose Veins	

	Musculoskeletal System Affected				
Occupation	**Muscular System**	**Skeletal System**	**Nervous System**	**Vascular System**	**Joint System**
Rock Driller			Foot-Vibration Syndrome		
Quarrier			Foot-Vibration Syndrome		
Welder			Foot-Vibration Syndrome		
Bush Cutter			Foot-Vibration Syndrome		
Grinder			Foot-Vibration Syndrome		
Wagon Driver			Foot-Vibration Syndrome		
Firefighter					Hip-Osteoarthritis, Knee-Osteoarthritis
Postal Worker					Hip-Osteoarthritis
Food Processing Worker					Hip-Osteoarthritis
Carpet/Floor Layer					Knee-Osteoarthritis, Meniscal disorder, bursitis
Manufacturing Worker					Knee- Carpet Layer's Knee
Taxi Cab Driver					Knee-Osteoarthritis
Professional Driver					Knee-Osteoarthritis
Construction Worker					Hip-Osteoarthritis, Knee-Osteoarthritis
Farm Worker					Knee-Osteoarthritis
Fishing Worker					Knee-Osteoarthritis

	Musculoskeletal System Affected				
Occupation	**Muscular System**	**Skeletal System**	**Nervous System**	**Vascular System**	**Joint System**
Civil Servant					Knee- Osteoarthritis
Dock Worker					Knee- Osteoarthritis
Tilesetter					Knee- Osteoarthritis, Bursitis
Forestry Worker					Knee- Osteoarthritis
Carpenter					Knee- Osteoarthritis
House Cleaning Worker					Knee- Osteoarthritis, Bursitis
Miner					Knee- Osteoarthritis, Meniscal Disorder, Bursitis
Millwright & Bricklayer					Knee- Osteoarthritis
Manufacturing Worker					Knee- Bursitis
Ballet Dancer		Thigh- Stress Fracture, Lower Leg- Stress Fracture, Foot- Stress Fracture			
Waiter/Waitress		Thigh- Stress Fracture, Lower Leg- Stress Fracture, Foot- Stress Fracture			
Medical Practitioner		Thigh- Stress Fracture, Lower Leg- Stress Fracture, Foot- Stress Fracture			
Wallpaper Hanger		Foot- Stress Fracture			
Chainsaw Operator			Foot- Vibration Syndrome		

Lower Extremity Postural Activity Discomforts

The term "Body Discomfort" when referring to body postures and activities, can be defined as any physical feeling or sensation of tingling, soreness, stiffness, numbness, or pain resulting from the combined biomechanical and fatigue variables of joint angles, muscle movements, and internal body pressures (Helander & Zhang, 1997; Kee & Karwowski, 2003; Meyer & Radwin, 2007). Postures holding the body in a cramped position can cause a fatiguing affect on the muscles used to hold that posture (Van Wely, 1970). Furthermore, LE muscle fatigue discomfort is also found as a result of long work periods with static postures and repeated activities (Corlett & Bishop, 1976). Joints themselves can be affected if sustained in extreme non-neutral angles (Van Wely, 1970) and blood flow can be constrained by sustained contact stress on body tissue (Chung, Lee, & Kee, 2005). The limiting or eliminating of high discomfort LE joint motions and body postures plays a major role in reducing the probability of WMSDs occurring to workers (Boussenna, Corlett, & Pheasant, 1982; Kee & Karwowski, 2003; Kee & Karwowski, 2004).

To maintain this goal, the focuses of postural research have been conducted on three fronts. The first is based on joint position and its affect on body discomfort. Examples of this focus can be seen as joint discomfort at angles of maximum joint range (Genaidy & Karwowski, 1993) or discomfort over intervals of range of motion (Kee & Karwowski, 2003). The second research focus is based on general or awkward body postures such as standing, sitting, or kneeling (Chung et al., 2005; Corlett & Bishop, 1976; Meyer &

Radwin, 2007). The last front is based on the association of activities to discomforts (McGlothlin, 1996; Pope, Hunt, Birrell, Silman, & Macfarlane, 2003). Examples of this association could be pushing, walking, lifting, etc.

Joint Position Discomforts

A study done by Kee and Karwowski (2003) looked at whole body joint discomforts noticed by participants as they moved their joints throughout a full range of motion. When pertaining to the LE, the hip, knee, and ankle were analyzed during standing and chair sitting postures. Each of these joint's discomfort ratings were taken at 0%, 25%, 50%, 75%, and at 100% of their maximum ranges. Each of these positions was held for 60 seconds. Joint degrees of freedom were also taken into account in this study in order to capture all possible movements.

Results of the study showed that hip motions tend to be the most uncomfortable for people to maintain, followed by ankle then knee joints as second and third, respectively. Kee and Karwowski (2003) noted that the highest discomforts were found during hip adduction and external rotation during standing postures. For sitting postures, hip flexion and external rotation were deemed most uncomfortable (Table 2-25).

Table 2-25 Lower extremity joint discomfort results from the study of Kee and Karwowski (2003)

Joint	Joint Motion	Sitting Posture	Standing Posture
Hip	Flexion	8	4
	Extension	NA	5
	Adduction	NA	8
	Abduction	4	5
	Internal rotation	5	5
	External rotation	8	8
Knee	Flexion	NA	2
Ankle	Dorsiflexion	3	3
	Plantar flexion	3	3
	Adduction	3	3
	Abduction	3	3

Larger numbers indicate higher levels of discomfort.

A similar but somewhat contrasting study was performed by Genaidy and Karwowski (1993). This study although similar in focus, only looked at levels of discomfort as they pertain to the maximum range of joint motion from a neutral position. Ankle dorsi and plantar flexions were the only ranges of motion included in the experiments. The results of the study were in agreement with Kee and Karwowski's (2003) assessment of the hip in relation to standing postures, in that it was deemed to have the highest overall levels of discomfort for the LE. Differences in results again were noticed for the discomfort levels of individual joint range of motions (Table 2-26).

Table 2-26 Lower extremity joint discomfort results from the study of Genaidy and Karwowski (1993)

Joint	Joint Motion	Sitting Posture	Standing Posture
Hip	Flexion	NA	4
	Extension	NA	3
	Adduction	NA	2
	Abduction	NA	5
	Internal rotation	NA	1
	External rotation	NA	1
Knee	Flexion	NA	NA
Ankle	Dorsiflexion	2	2
	Plantar flexion	1	1

Larger numbers indicate higher levels of discomfort.

Joint postural discomfort studies have also been conducted based on gender. Two whole body studies in particular looked at how standing posture and joint angles can affect discomfort for males (Kee & Karwowski, 2001) and females (Kee & Karwowski, 2004). Kee and Karwowski's (2001) male study also evaluated joints during sitting posture. Both studies took into account joint ranges of motion and degrees of freedom. Comfort ratings were obtained at intervals of 0%, 25%, 50%, 75%, and at 100% of maximum range of motion while holding positions for 60 seconds.

The conclusion of the study performed by Kee and Karwowski (2001) again confirmed that the hip joint is the most susceptible joint to discomfort for the LE for males while sitting or standing. Kee and Karwowski's (2004) female study concurred with its male counterpart study when referring to that of static hip postures. Additionally, they discovered that females are more comfortable with joint rotation postures such as external hip rotation than are males. The female study concluded that "female workers should be assigned jobs/tasks requiring smaller joint deviation, and/or less muscle force, and/or shorter task exposure and more breaks than males" (Kee and Karwowski, 2004, p. 444). It should be noted though that these results are under the constraints of a 60 second static hold, as well as one degree of freedom for one joint per rating. This leaves room for discrepancies such as not capturing discomforts with external loads or forces, repetitious movements, static posture durations longer than 60 seconds, and joint positions using more than one degree of freedom (Kee & Karwowski, 2001).

Body Posture Discomforts

Discomforts caused by occupational body postures can be divided into three groups. These groups are standing, sitting (assumed to be in chairs), and awkward or unusual postures (Gallagher, 2005). Gallagher (2005) continues by saying that awkward postures that are typically required for workers to use due to their task or physical environment are known as restricted postures (p. 51). Restricted postures listed are stooping, squatting, kneeling, and lying down (Gallagher, 2005). Additionally, although not included in Gallagher's (2005) listing, floor sitting and knee flexion can be assumed to also be included in the restricted postures listing as they may be used in such environments.

Standing

Standing as defined by Chung et al. (2003), is when the weight of the body is supported bilaterally through the legs to feet and the knee flexion angle is less than 30° from the vertical (p. 27). Multiple studies have examined the standing posture as it associates with discomforts and pains (Cham & Redfern, 2001; Chung et al., 2003; Messing et al., 2006; Redfern & Cham, 2000; Ryan, 1989; Van Wely, 1970). Prolonged standing greater than two hours was slightly associated to hip pain in one study (OR: 1.19; 95% CI: 0.8, 1.78) (Pope et al., 2003). Standing for long periods, especially with a pigeon-toed foot stance may lead to discomforts in the feet (Van Wely, 1970).

This was especially noticed in a study conducted for supermarkets with the aid of Australia's Victorian Occupational Health and Safety Commission (Ryan, 1989). Of the job titles and associated tasks observed, investigators of the study found that the checkout department (cashiers) held the highest rate of reported discomforts. A significant association was found between the long durations of sedentary standing required for the job (90% of work time) and the discomforts noticed in the lower leg and foot. In concurrence with Ryan (1989), Messing et al. (2006) found not just extended sedentary standing and lower leg/ankle/foot pain connections but also with combinations of standing and moving around short and long distances. Higher significance was noted though for prolonged standing postures that were fairly stationary in movement. Similar to Ryan (1989), these postures result in associations with the lower leg (OR: 3.69; 99% CI: 2.19, 6.23) and the ankle/foot (OR: 3.89; 99% CI: 2.53, 5.99) portions of the LE. In addition, another investigation found that cumulative standing for more than 30 minutes per hour led to overall LE discomfort (HR: 1.7; 95% CI: 1.0, 2.9).

Another study was conducted based on the hypothesis of flooring surfaces contributing to discomforts and fatigue (Cham & Redfern, 2001). Results of Cham and Redfern (2001) provided evidence that the environmental factor of the floor surface structure combined with long durations of standing posture (more than three hours), produces symptoms of discomfort in the lower legs as well as the lower back. It seems as far as floor surface construction is concerned, harder floors are more likely to produce discomfort (Redfern & Chaffin, 1995; Redfern & Cham, 2000). The variables involved with the floor's properties include the elasticity, stiffness, and thickness.

Some studies directed their objective to finding relationships between postures and discomforts explicitly for the lower extremity (Chung et al., 2003). In their research, Chung et al. (2003) divided standing postures into several subcategories that were basically derivations of distances between the feet (while parallel to shoulder breadth and from anterior-posterior heel distances). Of these, it was concluded that discomfort was especially noticed as the distance increased for the anterior-posterior postures.

Chair Sitting

In the research accomplished by Chung et al. (2003), it was noted that chair sitting is more comfortable than standing, squatting, kneeling, floor sitting, knee-flexing, and imbalanced postures. An overview on chair design and the affect they had on sitting discomfort was conducted in another study (De Looze, Kuijt-Evers, & Van Dieen, 2003). These investigators summarize that of the objective (direct) measurement methods available (electromyography, pressure distribution measurement, and postural analysis), pressure distribution statistically had the most significant association to psychophysical subjective ratings of discomfort. Additionally, they mention that the reasons behind this association may be due to body weight distribution in the seat pan and lumbar support in the back rest. Further studies detailing local discomforts have suggested that sitting on a chair without foot rests at an appropriate height level can cause discomfort in the knees and legs (Van Wely, 1970). Association between hip pain and prolonged chair sitting was also discovered in another study (Pope et al., 2003). The investigators found that this relationship existed when people were exposed to sitting tasks that lasted more than two hours (OR: 1.94; 95% CI: 1.28, 2.95).

Venous pooling or blood collection in the feet and lower legs is one noted side effect of sedentary sitting postures (Winkel & Jorgensen, 1986a; Winkel & Jorgensen, 1986b). In fact, this is noticed to occur within the first four hours of sitting with little or no leg activity (Winkel & Jorgensen, 1986b). Both studies conducted by Winkel and Jorgensen (1986a, 1986b) also include readings of decreased skin temperature along the foot and lower leg. Winkel and Jorgensen (1986a) noted that there is increased mean heart rate during sedentary sitting as well. A relationship also exists between the variables of foot swelling and the mean temperature of the flexor hallucis longus muscle which results in discomfort in the foot and lower leg (Winkel & Jorgensen, 1986a). Modest or intermittent leg activity is suggested as simple solutions to these discomforts.

Several studies have found that a relationship exists between knee discomforts and professional and taxi cab drivers in Taiwan (J. C. Chen et al., 2004; Taiwan Institute of Occupational Safety and Health (IOSH), 1999) and Norway (D. Anderson & Raanaas, 2000). Chen et al. (2004) showed that a significant association existed for taxi drivers who spent more than six hours per day driving (in sitting posture) and the knee pains they reported (OR: 2.52; 95% CI: 1.36, 4.65). The authors suggested that further longitudinal and biomechanical studies be conducted to provide reasoning for development of osteoarthritic knees from the stage of initial knee discomfort.

Awkward Postures

Stooping

Stooping postures involve bending of torso forward while keeping the knees straight. Meyer and Radwin (2007) reveal that stooping postures not only affect the lower back, but can also affect the LE. Areas of discomfort noticed include the hamstrings, front and back of the knees, front and back of the lower leg and feet. The majority of discomfort for this posture was observed to be in the hamstring region followed by the back of the knee (Meyer & Radwin, 2007).

Another study performed, focused on the discomforts of the LE and joint torques of the hip, knee, and ankle while in an awkward stooping posture (Boussenna et al., 1982). The stooping method applied, forced the participants to induce forward torso bending while keeping their knees straight. The degree of forward torso bending was based on four shoulder posture heights, each being based on a percentage of total shoulder height (meaning leaning forward at 100%, 75%, 50%, and 25% total shoulder height). Participants were asked to remain in the posture as long as their comfort allowed. Results of the study revealed that as the postures changed from a straight standing posture to a deep straight legged stoop, the posture balancing torques within each of the joints also increased. With the increase of a joint's torques, came an increase in reported joint discomfort and therefore decreased posture holding times. It was concluded from Boussenna's et al. (1982) study that the biomechanical torques of the body does affect the comfort of the LE. Aside from the discomfort noticed in the joints themselves, discomfort was perceived by participants to also radiate (superior and/or inferior) to proximal regions as well. Ankle torques influenced the discomfort of the lower leg, knee torques influenced both the thigh and lower leg regions discomforts and the hip torques affected the thigh and buttock region directly with the back also being indirectly affected.

Floor Sitting

Attention was pointed to floor sitting postures and their accompanying LE discomforts in one investigation (Chung et al., 2003). Three postures were analyzed; knees flexed and crossed, knees unflexed (0°) and legs straight anterior to the torso, and lastly, again the same position as the previous but with the knees flexed (90°). Results of their study indicated that the two latter postures showed more discomfort than sitting with knees fully flexed and crossed. It is proposed that this may be due to the lumbar region of the back being unsupported. Aside from Korea, it should also be noted that floor sitting is a common work related posture in other Asian countries such as India (Nag & Nag, 2007) and Thailand (Laohacharoensombat, Aekplakorn, Wanvarie, Wajanavisit, & Woratanarat, 2005).

Knee Flexion and Squatting

The postures of knee flexion and squatting can sometimes be confused with each other depending on the degree of flexion at the knee joint. Chung et al. (2003) differ between the two by saying that mild knee flexion is any position that is greater than 30° but less than 60° from the vertical axis. At the same time, their study used the same knee flexion angle of 60° as the top end threshold for severe knee flexion and 90° for the bottom end.

Squatting postures require the knees to be flexed greater than 90°. It should be noted that knee flexion and squatting postures do not include the contact of the knees on any surface. Results, of these postures indicate that mild knee flexion (≥ 30°), severe knee flexion (≥ 60°), and squatting all proved to be uncomfortable to the LE with discomfort increasing from one to the other, respectively.

Again, in a following study, postures involving knee flexion or squatting have been found to be a cause of high levels of overall LE discomfort (Chung et al., 2005). Knee flexion postures from Chung's et al. (2005) analysis varied between several positions. Their results coincide with the discomfort noticed in their previous study (Chung et al., 2003). As knee flexion increases from a standing posture of 0°, discomfort rises (Chung et al., 2005). At 90° of knee flexion and beyond, observations of discomfort levels climax. Conducted in Denmark, Andersen et al. (2007) become aware of the association between squatting for more than 5 minutes per hour and the resulting LE discomforts. In particular, they mentioned that the hip, knee, lower leg, and foot were affected areas (HR: 1.2; 95% CI: 0.8, 1.8).

Emphasis on the use of the squatting posture for greater than one hour may result in discomfort within the knee joint itself (Baker et al., 2003). Squatting has also been shown to produces discomforts in the thigh regions (Olendorf & Drury, 2001). It is hypothesized that general LE discomfort may be due to the large muscle groups of the quadriceps tightening as they contract to hold the body in these unbalanced postures (Boussenna et al., 1982; Chung et al., 2005; Olendorf & Drury, 2001). Therefore, holding squatting postures for more than 4 minutes at a time can lead to noticeable discomfort (Lee & Chung, 1999). Lee and Chung (1999) also mention that these squatting postures are common postures used by Korean workers in occupations such as ship and automobile manufacturing, farming, and machine repair shops.

Kneeling

Using a kneeling posture itself also creates a level of discomfort for people. The study of the resulting affects of kneeling and squatting postures in Asian and African occupations is an under-represented research area and further studies should be encouraged (Chung et al., 2003). Four kneeling postures were investigated by Chung et al. (2003). These postures were; kneeling with maximum knee flexion (sitting on lower legs and feet), kneeling with 90° of knee flexion, kneeling on one knee and kneeling in a crawling position. Full flexion kneeling and one knee kneeling represented the most uncomfortable postures for the LE. The crawling posture was considered to be the most comfortable of the kneeling postures from the study.

The kneeling posture is considered as much of an unbalanced position as it is considered a weight bearing one (Chung et al., 2005). One quickly noticed result from kneeling with the knees in a fully flexed position is that of numbness. Chung et al. (2005) believes this may be due to the body's weight compressing the vascular system of the LE resulting in restricted blood flow. Chung et al. (2005) concluded that kneeling is the most uncomfortable LE posture to assume based on their research in the Korean automotive manufacturing industry.

The previous two studies investigated kneeling postures as they relate to discomforts on the LE as a whole. Baker et al. (2003) noticed that pain in the knee itself could be connected to kneeling postures greater than one hour.

Tiptoeing

Chung et al. (2003, 2005), considers tiptoeing as a postural derivation of standing and therefore it is listed as a subcategory of it. Compared to standing though, Chung's et al. (2003) study revealed that tiptoeing while standing is significantly two times more uncomfortable to the LE than standard bilateral standing.

Imbalance

Chung et al. (2003, 2005) noticed that standing on one leg versus both legs is also an uncomfortable position for people to work in. Imbalanced postures in Chung's et al. (2003) study were caused by leaning the body's center of gravity to the right leg for one of four postures; one standing while medio-lateral distance was half of total shoulder width, a standing posture with anterior-posterior heel distances at one full foot-length apart, a knee flex posture with the knee flexion angle at 30°, and then a squat posture (knee flexion angle > 90°). The results of the study showed that again, the knee flexion angle influences discomfort. The two highest rated discomforts were imbalanced squatting followed by imbalanced knee flexion, respectively. Olendorf and Drury (2001) confirmed that imbalanced knee flexion posture does influence discomfort level in their validation study using OWAS' (Karhu et al., 1977) posture 5. Similar to the linear results of knee flexion to discomfort relationship, a linear relationship also seems to exist between that of LE discomfort and LE imbalance (LE discomfort increases with an increase in LE imbalance) (Chung et al., 2005).

Activity Discomforts

Tasks involving manual material handling and manipulation of the upper extremities ultimately affect how the segments and joints of the LE will position themselves. A task may consist of several postures such as standing or squatting as well as several activities such as walking or lifting. In these cases association of LE discomfort to one distinct posture or activity would not be possible. An example of this can be seen with a study performed for soft drink beverage delivery employees (McGlothlin, 1996). Several body regions were reported to have discomforts but the majority of the discomforts reportedly affects the knees. Further investigation reveals that the delivery employees utilized postures of sitting (from driving), kneeling and squatting as well as activities of pushing, pulling, lifting, lowering, stacking/unstacking, walking, and climbing (stairs or ramps). Stair climbing in particular, has been noted to exert quantities of force that are close to the weight of the person as a shear force in the anterior-posterior knee direction (Costigan, Deluzio, & Wyss, 2002). Costigan et al. (2002) also mention that compressive forces in the knee along the superior-posterior direction can amount anywhere from 3 to 6 times the body weight of the person.

In agreement with McGlothlin's (1996) manual material handling correlation, was another study connecting discomfort to a specific load weight and duration (Pope et al., 2003). Pope's et al. (2003) epidemiological study of workers and the cumulative length of their exposure, noticed that lifting or moving objects in excess of 23 kilograms (50 pounds) for durations of more than 13 years was associated with hip discomforts (OR: 1.90; 95% CI: 1.30, 2.78). Additionally, they observed that walking activities were again identified to be a cause of discomforts to the hip joint (Pope et al., 2003). Pope et al. (2003) noted that the combined risks of walking, duration, and repetition were the basis for this argument. Walking more than 2 miles per day for more than 15 years was one association found (OR: 1.65; 95% CI: 1.13, 2.41), and the other resulting from walking more than 2 miles per day for more than 7 years on rough surfaces (OR: 2.65; 95% CI: 1.43, 4.90). Hip pain and stair climbing was also noted by Pope et al. (2003) to be associated when workers were exposed to more than 20 flights of climbing per work day (OR: 1.40; 95% CI: 0.87, 2.25). In particular, this connection to people whose exposure level was for greater than 14 years.

An investigation (n = 5042) carried out in the United Kingdom looked for LE risk-discomfort relationships among post office workers aged 70-75 years old (Sobti, Cooper, Inskip, Searle, & Coggon, 1997). Examiners observed that workers exposed to lifting items greater than 25 kilograms (55 pounds) had an association to hip discomfort (RR: 1.50; 95% CI: 1.24, 1.82). Additionally, they also mention that the exposure of climbing more than 30 flights of stairs per day led to an association of knee discomfort (RR: 1.17; 95% CI: 0.99, 1.38). Details of the association's results find that workers are exposed to these work requirements throughout their work-related experiences which varied between 1 and 15 years. Andersen et al. 2007 discovered that a relationship also existed for LE discomforts and the acts of pushing and pulling objects. Specific detail of the results of the study reveal that pushing and pulling objects that exceed the cumulative weight of 355 kilograms (782.6 pounds) per hour affects the discomfort in the hip, knee, and foot areas of the LE (HR: 1.6; 95% CI: 1.0, 2.5).

A study (n = 7770) conducted for the working population in Quebec, Canada, looked at LE discomforts noticed within the past 12 months by working men and women between 18 and 65 years of age (Messing et al., 2006). Messing et al. (2006) mention that associations exist between women's lower leg and ankle/foot pains and repetitive hand work and manual material handling involving weighty objects. Hand and arm repetition activities related to both lower leg pain (OR: 1.50; 99% CI: 0.90, 2.49) and ankle/foot pain (OR: 1.73; 99% CI: 1.11, 2.70). Heavy load handling unfortunately was not given a quantity as to how much weight was considered by the investigators to be "heavy". The measures for this risk are OR: 2.56; 99% CI: 1.30, 5.04 and OR: 1.76; 99% CI: 0.93, 3.31 for the lower leg and ankle/foot, respectively. For men, their study revealed lower leg and ankle/foot pains associated to activities that involved whole body vibration exposure. This is shown to have a relationship of OR: 3.48; 99% CI: 1.92, 6.32 and OR: 2.40; 99% CI: 1.40, 4.10 for the lower leg and the ankle/foot segments accordingly.

Summary

The subjective response to body discomfort depends on the physical capacities of the person being observed (De Looze et al., 2003). De Looze et al. (2003) continues by mentioning that the posture being used by a person (sitting, in the case of their study), the environment, and the task all have a part to play in the subjective decision of discomfort level. This can be interpreted as an external multi-variable trigger leading to discomfort. This relationship can be seen throughout the course of this section's review of past literature in the forms of joint position, body posture, and task activities. It should not be surprising to see that some of these postural activity risks may represent the same resulting ones noticed in prior sections. It is the objective of this review to document and quantify the variables that represent a risk to the LE for development of discomforts as well as WMSDs. Acknowledging and understanding the occupations in industries will allow ergonomic and medical practitioners to refine their scopes of research (Table 2-27). The results of this section's review can aid in the development of a discomfort guideline of threshold limitations for future study and job/task development and redesign (Table 2-28).

Of the studies that were reviewed, Table 2-29 describes that the majority of research has been conducted for the standing and sitting postures. Squatting, kneeling, and imbalance studies are less popular. Tiptoeing, knee flexion, stooping, and lay down occupational postures seem to be the least studied postures when relating to LE discomforts. Lay down postures can be used while prone, supine, or on one's side. Future studies of these postures' influence on employees in occupational settings should be made in future studies. Of the activities that associate to discomforts for the LE, manual material handling tasks such as lifting, lowering and stacking are accompanied by the activity of walking as the most scrutinized (Table 2-30).

Location of LE body discomfort has been primarily pinpointed to the LE as a whole (Table 2-31). The knee, lower leg, and foot are the most dominant regions affected occupational postures with the buttocks and ankle being the least. Hip pains are noted as the most common discomforts associated to activities, followed by the lower leg, ankle and foot (Table 2-32). The listed studies in Table 2-31 indicate that stooping postures seem to affect the lower extremity in the most locations followed by squatting, standing, and chair sitting. Table 2-32 indicates that walking, pushing, and pulling are associated to a majority of body discomforts. It should be noted that not all sources in this compilation included specific LE body locations. So other postures and activities listed may be just as uncomfortable and affect as many LE areas as a stooping posture.

Table 2-27 Occupations noted to be associated with lower extremity discomforts and postural activities

Occupation	Body Location	Source
Cashiers	Lower Leg, Foot	Ryan, 1989
Taxi Cab Drivers	Knee	D. Anderson & Raanaas, 2000; J. C. Chen et al., 2004; Taiwan Institute of Occupational Safety and Health (IOSH), 1999
Professional Drivers	Knee	Taiwan Institute of Occupational Safety and Health (IOSH), 1999
Beverage Delivery Workers	Knee	McGlothlin, 1996
Post Office Workers	Hip	Sobti et al., 1997

Table 2-28 Guideline based on quantities captured by investigators during discomfort research and epidemiological study

Posture or Activity	Continuous Exposure Quantity	LE Body Area Affected	Source
Standing (anterior-posterior foot stance)	> 14.6 in (between heels)	LE	Chung et al., 2003
Standing	> 2 hrs / incident	Hip	Pope et al., 2003
Standing	> 2 hrs / incident	LE	Cham & Redfern, 2001
Chair Sitting	> 2 hrs / incident	Hip	Pope et al., 2003
Chair Sitting	> 4 hrs / incident	Lower Leg; Foot	Winkel & Jorgensen, 1986b
Chair Sitting (while driving)	> 6 hrs / incident	Knee	J. C. Chen et al., 2004
Squatting	≥ 90° of knee flexion	Thigh	Cham & Redfern, 2001
Squatting	> 5 min / hr	Hip; Knee; Foot	Andersen, Haahr, & Frost, 2007
Squatting	> 4 min / incident	LE	Lee & Chung, 1999
Lifting & Lowering	> 50 lbs / item	Hip	Pope et al., 2003
Pushing & Pulling	> 782.6 lb / hr	Hip; Knee; Foot	Andersen et al., 2007
Walking	> 2 miles / work day	Hip	Pope et al., 2003
Stair Climbing	> 20 flights / work day	Hip	Pope et al., 2003
Stair Climbing	> 30 flights / work day	Knee	Sobti et al., 1997

Table 2-29 Studies that have been conducted involving postures that have been noted to cause discomforts to the lower extremity

	Posture									
Source	Standing	Stooping	Chair Sitting	Floor Sitting	Knee Flexion	Squatting	Kneeling	Tiptoeing	Imbalance	Lying Down
D. Anderson & Raanaas, 2000			X							
Andersen et al., 2007						X				
Baker et al., 2003						X	X			
Boussenna et al., 1982		X								
Cham & Redfern, 2001	X									
J. C. Chen et al., 2004			X							
Chung et al., 2003	X		X	X	X	X	X	X	X	
Chung et al., 2005				X	X	X	X	X	X	
Corlett & Bishop, 1976										
De Looze et al., 2003			X							
Genaidy & Karwowski, 1993										
Helander & Zhang, 1997										
Kee & Karwowski, 2001	X		X							
Kee & Karwowski, 2003										
Kee & Karwowski, 2004										
Lee & Chung, 1999						X				
McGlothlin, 1996			X			X	X			
Messing et al., 2006	X									
Meyer & Radwin, 2007		X								X
Olendorf & Drury, 2001						X			X	
Pope et al., 2003	X		X							
Redfern & Cham, 2000	X									
Ryan, 1989	X									
Sobti et al., 1997										
Taiwan Institute of Occupational Safety and Health (IOSH), 1999			X							
Van Wely, 1970	X		X							
Winkel & Jorgensen, 1986a			X							
Winkel & Jorgensen, 1986b			X							

Table 2-30 Studies that have been conducted involving activities that have been noted to cause discomforts to the lower extremity

	Activity						
Source	Walking	Pushing	Pulling	Lifting	Lowering	Stacking	Stair/Ramp Climbing
D. Anderson & Raanaas, 2000							
Andersen et al., 2007		X	X				
Baker et al., 2003	X						
Boussenna et al., 1982							
Cham & Redfern, 2001							
J. C. Chen et al., 2004							
Chung et al., 2003							
Chung et al., 2005							
Corlett & Bishop, 1976							
De Looze et al., 2003							
Genaidy & Karwowski, 1993							
Helander & Zhang, 1997							
Kee & Karwowski, 2001							
Kee & Karwowski, 2003							
Kee & Karwowski, 2004							
Lee & Chung, 1999							
McGlothlin, 1996	X	X	X	X	X	X	X
Messing et al., 2006				X	X	X	
Meyer & Radwin, 2007							
Olendorf & Drury, 2001							
Pope et al., 2003	X			X	X	X	X
Redfern & Cham, 2000							
Ryan, 1989							
Sobti et al., 1997				X	X	X	X
Taiwan Institute of Occupational Safety and Health (IOSH), 1999							
Van Wely, 1970							
Winkel & Jorgensen, 1986a							
Winkel & Jorgensen, 1986b							

Table 2-31 Posture associations to lower extremity discomfort body regions

	Joint or Segment Discomfort Location								
Posture	Lower Back	Hip	Thigh	Buttock	Knee	Lower Leg	Ankle	Foot	Overall LE
Standing		X				X	X	X	X
Stooping	X		X	X	X	X		X	
Chair Sitting		X			X	X		X	X
Floor Sitting	X								X
Knee Flexion									X
Squatting		X	X		X	X		X	X
Kneeling					X	X			X
Tiptoeing									X
Imbalance									X
Lying Down									

Table 2-32 Activity associations to lower extremity discomfort body regions

	Joint or Segment Discomfort Location								
Activity	Lower Back	Hip	Thigh	Buttock	Knee	Lower Leg	Ankle	Foot	Overall LE
Walking		X			X	X	X	X	X
Pushing		X			X	X	X	X	X
Pulling		X			X	X	X	X	X
Lifting		X				X	X	X	X
Lowering		X				X	X	X	X
Stacking		X				X	X	X	X
Stair/Ramp Climbing		X			X				X

Work-related Musculoskeletal Disorder & Discomfort Risk Variables

Founding concrete explanations of the personal and occupational contributing factors can help determine the risks of a subject, task, or environment. OSHA reveals that an explanation of the reason the injury or illness is work-related can be accomplished through medical examination, patient medical and injury history, job/task analysis, and off the job contributing factors (Occupational Safety & Health Administration, 2002). Additional studies have concurred with OSHA that ultimately these disorders may develop through combinations of personal factors (such as medical and injury history) with occupational factors (such as task procedures and psychosocial affecters) (Armstrong et al., 2001; McCauley-Bell & Badiru, 1992; McCauley-Bell & Badiru, 1996; McCauley-Bell & Crumpton, 1997; Warden et al., 2006).

Personal Risk Factors

A compilation of personal risk factors can be derived from longitudinal and cross-sectional retrospective and prospective studies. The focus of these studies results in two groups of personal risk factors: individual physiological risks associated with a person's physical body and individual psychosocial risks associated with a person's mental condition.

Personal Physiological Risk Factors

Likelihood of future development of WMSDs with respect to personal physiological risk can be attributed to three major risk areas (Table 2-33). The first is a history of previous injuries or illnesses to the region of the body in question. Research has shown that past injuries or illnesses can influence the occurrence or re-occurrence of future development of WMSDs (Washington State Legislature, 2000). It may be possible that this is due to the physiological changes that occurred from the extent of exposure and body location of the original event. Relative risk can also be increased through personal health disorders such as hereditary genetics, diabetes, arthritis, and pregnancy (Cole & Rivilis, 2006; Hansen, 1993; McCauley-Bell & Badiru, 1996).

Internal biomechanics of the body also play a role as a personal risk. Throughout the locomotion process, the body is constantly cycling through internal forces that stress the musculoskeletal system into performing the desired movement. Each part of the system has an influence on the other to a certain extent such as a muscles pull on a bone surface over a joint (Warden et al., 2006). Quantification of this biomechanical influence can theoretically aid in achieving a more accurate risk assessment. Understanding the direct biomechanical results of physical task objectives can also indirectly act as an association tool between these task objectives and the WMSDs and discomforts incurred by workers.

The last personal risk factor is the physical fitness of an individual. Multiple studies have been conducted to determine the influence of physical fitness' association to WMSD prevention such as lower extremity stress fractures in the military occupations (Trone, Villasenor, & Macer, 2007; Warden et al., 2006). In occupations outside of military and athletics, it may be possible to assess physical fitness through the discipline provided by an industrial athletics program. In this form of occupational therapy, workers' physical fitness and treatment are considered in the same respects as a military recruit or sports athlete (Sevier, Wilson, & Helfst, 2000).

Table 2-33 Personal physiological risk factors that may influence the overall risk for acquiring WMSDs

Personal Physiological Risk Factors
Musculoskeletal System - Medical & Injury History
Internal Biomechanical Risk Factors
Physical Fitness

Personal Psychosocial Risk Factors

Many of the techniques used within ergonomics focuses on solving the physical issues associated with the tasks and the resulting disorders encountered. Besides this, psychosocial factors such as stress, anxiety, and fear (see Table 2-34) can also play a role in influencing and exacerbating problems (National Research Council Panel on Musculoskeletal Disorders and the Workplace, 2006). It should be noted that these risks are associated to musculoskeletal occupational back incidents and may or may not be directly related LE WMSDs.

Table 2-34 Personal psychosocial risk factors that may influence the overall risk for acquiring WMSDs (National Research Council Panel on Musculoskeletal Disorders and the Workplace, 2006)

Personal Psychosocial Risk Factors
Depression or Anxiety
Psychological Distress
Personality Factors
Fear-Avoidance-Coping
Pain Behavior/Function

Occupational Risk Factors

A job/task analysis is an attempt to catalogue and quantify the personal and occupational risks that the body might endure at work. Common occupational risks can be summed into what is known as the "Seven Sins" in ergonomics (Kroemer, 1997)(p. 18). They include activities involving any of the following:

1. Repetitive motion
2. High force or overexertion
3. Extreme or awkward postures

4. Static postures
5. Compression or pinching of body tissue by equipment or environment
6. Tool or environment vibration
7. Exposure of parts or all of the body to cold environments

In addition to these risks, duration of exposure during a task (Crumpton-Young et al., 2000; Hansen, 1993), weight of material being handled, hand grip (load coupling), recovery time (or lack of) between tasks, and even activity type (David, 2005) have also been noted in studies. All together, sub-groups of occupational risks can be seen in the form of posture, activity, or environmental factors.

Occupational risks and LE WMSDs relationships have been noticed in many studies as noted in prior sections of this chapter. As a precursor in some situations to reportable WMSDs, LE discomforts have been previously discussed and shown to be linked to a variety of postural activities such as standing, sitting, kneeling, squatting, leaning, and even tiptoeing postures as well as manual material handling activities such as heavy lifting. Risk postures that include contact stress (such as kneeling or using the knee as a hammer) or high frequencies of kneeling, and squatting have been linked to discomforts and WMSDs for many of the studies reviewed in the LE WMSD and Discomfort sections. Tiptoeing and imbalanced standing also causes discomforts (Chung et al., 2003; Chung et al., 2005). Heavy lifting during manual material tasks has been associated to hip osteoarthritis (Yoshimura et al., 2000). Details of these relationships have been previously discussed in this chapter under the sections LE WMSDs and LE Postural Activity Discomforts.

Either excessive exposure to one risk or a combination of the fore mentioned risks can increase overall relative risk and produce acute or chronic signs and symptoms within the body (Figure 2-10). In reference to the LE, many of the occupational tasks that do lead to WMSDs involve the risk of tissue compression against tool and work surfaces (Lavender, 2006), thereby leading to many of the joint disorders listed previously. An overview of the occupational and personal risk relationships and their associated disorders and discomforts is displayed in Tables 2-35 and 2-36.

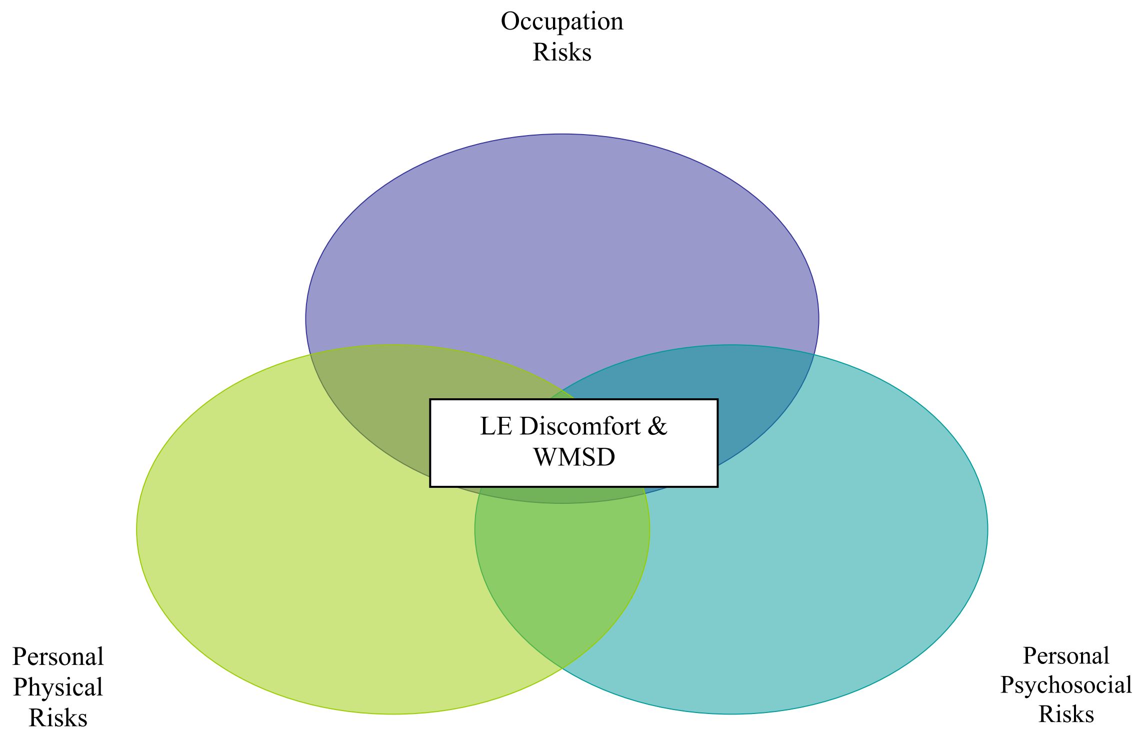

Figure 2.10 The Venn diagram displays how lower extremity discomforts and WMSDs are multidisciplinary combinations of variables from personal physical and psychological risks and occupational risk categories

Table 2-35 Occupational postural risks and their associated lower extremity WMSD or discomfort

	Occupational Risk												
	Posture												
Resultant Effect	Standing	Tip-Toeing	Imbalan-ced Standing or Leaning	Floor Sitting	Chair Sitting	Leg Crossing (while sitting)	Stoo-ping	Knee Flexion, Crouching or Squatting	Knee-ling	Standing up from kneeling or squatting	Lying Down	Tissue Compre-ssion On or Against Work Surface	Certain Joint Positions
Iliotibial Band Syndrome										X			
Plantar Fasciitis	X												
Stress Fracture			X										
Lateral Femoral Cutaneous NE			X								X		
Common Peroneal NE			X			X		X					
Superfi-cial Peroneal NE								X	X				
Deep Peroneal NE				X									
Digital NE									X				

Muscular System WMSD
Skeletal System WMSD
Nervous System WMSD

	Occupational Risk												
	Posture												
Resultant Effect	Standing	Tip-Toeing	Imbal-anced Standing or Leaning	Floor Sitting	Chair Sitting	Leg Crossing (while sitting)	Stoo-ping	Knee Flexion, Crouching or Squatt-ing	Knee-ling	Standing up from kneeling or squatting	Lying Down	Tissue Compre-ssion On or Against Work Surface	Certain Joint Posi-tions
Varicose Veins	X				X								
Vibration Syndrome													
Ischemia					X							X	
Hip OA	X							X	X				
Knee OA								X	X				
Meniscal Disorder	X							X	X	X			
Knee Bursitis									X			X	
Discom-fort	X	X	X	X	X		X	X	X		X		X

Vascular System WMSD

Joint System WMSD

Table 2-36 Occupational activity and environmental risks and their associated lower extremity WMSD or discomfort

	Occupational Risk												
	Activity										**Environmental**		
Resultant Effect	Walk-ing	Runn-ing	Jump-ing	Push-ing or Pull-ing	Lifting, Lowering or Carrying	Stack-ing	Using the knee as a hammer	Stair, Ladder or Ramp Climb-ing	Vibra-ting Tool Usage	Sports	High Temperature or Humidity	Equip-ment Tissue Constriction	Vibrat-ing Work Surface
Iliotibial Band Syndrome													
Plantar Fasciitis	X	X											
Stress Fracture		X	X										
Lateral Femoral Cutaneous NE												X	
Common Peroneal NE												X	
Superficial Peroneal NE													
Deep Peroneal NE												X	
Digital NE													

Muscular System WMSD
Skeletal System WMSD
Nervous System WMSD

	Occupational Risk												
	Activity										Environmental		
Resultant Effect	Walk-ing	Runn-ing	Jump-ing	Push-ing or Pull-ing	Lifting, Carrying	Stack-ing	Using the knee as a hammer	Stair, Ladder or Ramp Climb-ing	Vibra-ting Tool Usage	Digging	High Temperature or Humidity	Equip-ment Tissue Constric-tion	Vibrat-ing Work Surface
Varicose Veins											X		
Vibration Syndrome									X				X
Ischemia												X	
Hip OA			X	X	X			X	X	X			
Knee OA	X				X			X	X				X
Meniscal Disorder	X				X			X					
Knee Bursitis							X						
Discom-fort	X			X	X	X		X					

Vascular System WMSD

Joint System WMSD

Table 2-37 Personal risks and their association to WMSDs

	Personal Risk								
WMSD	Leg Length Discrepancy	Excess Tibial Rotation	Bow Legged	Pes Planus	Pes Cavus	Excess External Hip Rotation	High Q-angle	Low Physical Fitness	Secondary Amenorrhea (women)
Iliotibial Band Syndrome	X	X	X						
Plantar Fasciitis	X	X		X	X				
Stress Fracture	X					X	X	X	X
Lateral Femoral Cutaneous NE	X								
Common Peroneal NE									
Superficial Peroneal NE									
Deep Peroneal NE									
Digital NE									

Muscular System WMSD
Skeletal System WMSD
Nervous System WMSD

	Personal Risk				
WMSD	Narrow Tibia	Foot Over-pronation	Excess Femoral Antiversion	Low Dorsiflexion Displacement	Diabetes
Iliotibial Band Syndrome		X			
Plantar Fasciitis				X	
Stress Fracture	X				
Lateral Femoral Cutaneous NE					X
Common Peroneal NE					X
Superficial Peroneal NE					
Deep Peroneal NE					
Digital NE					

Muscular System WMSD
Skeletal System WMSD
Nervous System WMSD

	Personal Risk							
WMSD	Sudden Weight Loss	Sudden Weight Gain	Obesity	Vascular Disorder	Thyroid Disorder	Female Gender	Current/ Past Pregnancy	Bowel Strain
Iliotibial Band Syndrome								
Plantar Fasciitis			X					
Stress Fracture								
Lateral Femoral Cutaneous NE		X			X			
Common Peroneal NE	X			X	X			
Superficial Peroneal NE								
Deep Peroneal NE								
Digital NE								
Ischemia								
Vibration Syndrome								
Varicose Veins			X			X	X	X
Hip OA			X					
Knee OA			X					
Meniscal Disorder								
Knee Bursitis								

Muscular System WMSD
Skeletal System WMSD
Nervous System WMSD
Vascular System WMSD
Joint System WMSD

	Personal Risk						
WMSD	Age	Heredity	Height	Race	Smoking	Past Injury	Physically Intensive Habits/Hobbies
Iliotibial Band Syndrome							X
Plantar Fasciitis							
Stress Fracture							
Lateral Femoral Cutaneous NE							X
Common Peroneal NE							
Superficial Peroneal NE							
Deep Peroneal NE							
Digital NE							
Ischemia							
Vibration Syndrome							
Varicose Veins	X	X	X	X	X		
Hip OA	X					X	X
Knee OA	X					X	X
Meniscal Disorder							X
Knee Bursitis							

Muscular System WMSD
Skeletal System WMSD
Nervous System WMSD
Vascular System WMSD
Joint System WMSD

Lower Extremity Analysis Screening Tools and Models

The vast majority of risk assessment models/tools that include the lower extremity regions are intended to be for whole body use and not lower extremity alone. These tools take into account several risk factor groups in order to give an overall aggregated risk score. David (2005) mentions that possible risk factors can be grouped in categories such as posture, load (weight) or force, activity frequency, task/activity duration, recovery time, vibration, compression, load coupling, psychosocial, environmental, and individual (personal) factors to name a few. Of these, Li and Buckle (1999) mention that activity frequency, task duration and additionally force intensity (magnitude) are three major factors commonly employed to measure physical workload (Li & Buckle, 1999). The risk assessment tools, depending on their complexity will use at least one if not more of these categories, with posture being the risk category most frequently observed (Li & Buckle, 1999). Hence, the majority of the following 13 models described will be based on postural assessment methods.

The postural risk category is considered and recorded as the oldest method of observing human movement (Corlett et al., 1979; Hutchinson, 1966; Priel, 1974). It is believed that the ancient Egyptians documented dance choreography through the use of hieroglyphs (Hutchinson, 1966). Interesting enough, Hutchinson (1966) continues on by saying that available evidence of the recording of human movement stems from the fifteenth century (Hutchinson, 1966). The sixteenth century brought about the involvement of sketches accompanied by description. In seventeenth century France, a recorded method was shown to be developed and implemented by Raoul Feuillet for use in classical ballet. More recently, the appliance of the Benesh Dance Notation (Benesh & Benesh, 1956) and Labanotation (Hutchinson, 1966; Laban, 1971) have become the staples for dance choreography by methods of symbolic coding in a manner similar to writing music. These latter methods of dance choreography are considered impractical for industrial occupational settings due to an extensive learning curve (three months minimum) as well as the prolonged time needed to complete an assessment (Corlett et al., 1979; Kember, 1976).

WMSDs, pain, discomfort, and work postures have been shown to be connected with each other when pertaining to the lower extremity (Leonard & Keyserling, 1989). In addition, it was noted that past research models for the lower extremity were only descriptive in nature to the function of the body region (lower extremity joints) and did not take into account the relation of WMSDs to posture or usage. When pertaining to using postural analysis as a tool Karhu et al. (1977) ask two significant questions:

1. "What is the most feasible way of analyzing postures" (p. 199)?
2. "How does one know which postures are the poor ones…" (p. 199)?

Priel – Posturegram – 1974

The Posturegram was one of the first tools developed to numerically quantify the body's postures in an occupational setting following the Banesh Movement Notation and Labanotation (Priel, 1974). Priel (1974) viewed posture assessment as a 3D notion. Using the sagittal/lateral (yz), frontal (xz), and transverse/horizontal (xy) planes, movements were dimensionally recorded for each joint bilaterally (left and right side) for the limbs (including hips, knees, ankles, and toes for the lower extremity) and unilaterally for the neck and trunk (14 total joints) onto a Posturegram card. Limb segments between joints are also assessed by angle of inclination (LE segments include thighs, legs, and feet). By creating a standard base posture, Priel (1974) was one of the first to show interest in postural deviation from a start position. The Posturegram tool (1974) quickly shows when a limb is not in standard position because it is notated and numbered as positive (+) or negative (-) posture for the left or right side body sections. In the dimensional plane sections, degrees of deviation from standard joint posture are given in 15° incremental approximations.

Corlett et al. (1979) as well as Gil and Tunes (1989) advise that even though the Posturegram method is simple and digitally recordable onto computers, the system requires a large number of data entries (approximately 40) for each joint's dimensional posture, additional notes for activity, posture descriptions, and a postural sketch. This process takes several minutes until completion (Foreman, Davies, & Troup, 1988). Li and Buckle (1999) also point out that the Posturegram method involves using multiple Posturegram cards (snapshots) to record the progression of postures throughout a given task. The intent for the tool is for the practitioner to identify and focus on what they deem a critical posture; therefore, use of it for dynamic assessment cases would be time consuming.

Karhu et al. – OWAS – 1977

Developed initially for a company in the Finland steel industry, the Ovako Working Posture Analysing System (OWAS) (Karhu et al., 1977) was designed to assess these working posture and loads for a task (David, 2005). The OWAS system became a programmed software in the 1990's and is sometimes referred to as computerized OWAS (COWAS) when utilized (Kivi & Mattila, 1991).

The OWAS tool evaluates total body risk by examining the back, upper extremities and lower extremities. This is accomplished by allowing the evaluator to choose from a listing of possible postures from each group as well as the force or load effort needed for the task (Table 2-37). Four postures are given for the back and ranked (1-4) for increasing risk and discomfort with 1 being the most comfortable and lowest risk to the musculoskeletal system. The same approach is applied to the upper extremities with a range of 1-3. In particular to the lower extremity regions, consideration is given for unilateral or bilateral appendage usage and has seven possible postures ranked 1-7. The fourth range (for force or load effort needed) is ranked 1-3. These number ranges are combined into a four digit number set listed from back rank to load rank (e.g., 4321) (Mattila et al., 1993).

Table 2-38 OWAS risk groups such as body regions (postures) and task forces (weights) that combine to comprise the total body four digit number (Mattila et al., 1993)

Body Region	Posture or weight	Risk Rank
Back	Straight	1
	Bent	2
	Twisted	3
	Bent & twisted	4
Upper Extremities	Both below shoulder height	1
	One above shoulder height	2
	Both above shoulder height	3
Lower Extremities	Sitting	1
	Both legs straight (standing)	2
	One leg straight (standing)	3
	Both legs bent (full squat)	4
	One leg bent	5
	Kneeling	6
	Walking	7
Force or load effort	≤ 10 kg (22.05 lbs)	1
	≤ 20 kg (44.09 lbs)	2
	> 20 kg (44.09 lbs)	3

Corrective action categories are given a rank from 1-4 with 4 being the highest risk to the musculoskeletal system from the task (Table 2-38). Subjective evaluations of each task's four digit code are then categorized into one of the four action categories based on the combined posture's and load's effect on the musculoskeletal system (Mattila et al., 1993). This will allow the filtering out of the more acceptable tasks and expose the tasks that are more likely to cause WMSDs.

Table 2-39 OWAS action categories (Mattila et al., 1993)

OWAS action category	Description
1	Combined postures and loads are considered least likely to cause harm to the musculoskeletal system. No action needed.
2	Combined postures and loads pose minimal risk. No immediate changes necessary but should be contemplated for the future.
3	Combined postures and loads are considered a moderate risk to the musculoskeletal system. Changes should be considered and made soon to postural methods.
4	Combined postures and loads are considered a high risk to the musculoskeletal system. Abrupt changes should be made to postural methods.

One pitfall of the OWAS method mentioned by Corlett et al. (1979) is that the system is incapable of differentiating between postures of the same resulting four digit number. They continue by saying that if one posture needs to be evaluated from several occasions, then the more serious risk of the set may be ambiguous.

Corlett et al. – Posture Targetting – 1979

Another posture assessment tool developed is Posture Targetting (Corlett et al., 1979). Corlett et al. (1979) designed the system to incorporate the multiple regions of the body (head, torso, upper/lower arms, and upper/lower legs). Positions and body direction (anterior or posterior) are recorded using ten "segmented concentric circles or targets" that are located next to each of their associated region (Corlett et al., 1979, p. 359). Similar to the goniometric method applied by Priel (1974), Corlett et al. (1979) show body region deviation from a standard standing start posture. Regional targets are written on when it is noticed that the particular posture is in a different position than that of the standard standing posture shown. Along with each region's position is the option to record the activity that accompanies it. This is done by checking off particular activities that associate with the given posture of the region they accompany. The choices available from the activities list are; crank, strike, push, pull, hold, weight, squeeze, twist, wipe, and walk.

Time-sampling is the observational method proposed by Corlett et al. (1979) to capture activities dynamically. Subsequent studies (Foreman et al., 1988; Li & Buckle, 1999) counter this proposal though by commenting that Posture Targetting is most applicable towards static posture assessment rather than dynamic due to the amount of time it takes to capture the necessary information (approximately 30 seconds).

Holzmann – ARBAN – 1982

Another whole body assessment tool developed, is known as ARBAN (Holzmann, 1982). Used primarily in Sweden's building construction industry (Pinzke, 1997), this tool looks individually at different regions of the body such as the 1) head and neck, 2) right shoulder and arm, 3) left shoulder and arm, 4) trunk and back, 5) the right leg, and 6) the left leg (Holzmann, 1982). Tasks are captured via video capture and analyzed using a time-sampling observational method on a computer. The leg regions of the LE are examined as a whole.

ARBAN is different from most observational posture assessment tools in that aside from posture, it also includes the risk factors of dynamic muscle forces, static (isometric) muscle loads, and vibration. Based on the practitioner's judgment of these risks throughout the task, quantities are given using psychophysical perceived exertion or effort (Borg, 1985) known as Rate of Perceived Exertion (RPE). Borg's (1985) scale ranges from 0 to 10 with 0 representing no stress noted and 10 being the maximum effort required. From here, ARBAN uses computer software to generate graphs that compare the total body effort to times throughout the task period. Graphs can also be generated to display body region components' association to the stresses noticed during the task.

Kemmlert & Kilbom – PLIBEL – 1987

A checklist was developed by Kemmlert and Kilbom (1987) so that ergonomic practitioners could determine which tasks may contribute to WMSDs. This checklist is known as the *Method for identification of musculoskeletal stress factors which may have injurious effects* (PLIBEL). Designed and tested in Sweden, PLIBEL has been used in a variation of environments from manufacturing industries to service industries (for instance carpentry and baking) (Kemmlert, 1995).

The methodology behind the design of the PLIBEL checklist divides the body into five regions used to identify areas of the musculoskeletal system affected by the tasks at hand. These regions include the 1) neck, shoulders, and upper back, 2) elbows, forearms, and hands, 3) feet, 4) knees and hips, and 5) lower back. The checklist includes a list of seventeen total "yes/no" questions that relate in nature to the individual body regions. Not all seventeen questions relate to each body region. Some questions are general in nature and are used for each region, whereas others are specific to a particular body region. This determination was made in the development of PLIBEL through literary research (Kemmlert, 1995). Kemmlert (1995) continues by saying that this tool can be used in an implicit or explicit manner. This means that one can use PLIBEL as a screening tool to check if any body regions are affected by a task or it can be used to check a task for a specific body region that is under suspicion.

Conclusions for risk assessments using PLIBEL are not based on a quantifiable figure but instead are based on whether a situation does or does not exist. This aids in identifying the activities that are involved in task that may be causing WMSDs to develop. In relation to the LE, the questions detailed for the feet and knee/hip regions are located in Table 2-39. Kemmlert (1995) notes that one downside to the tool is that the inter-observer reliability is not considered high which causes variations between observer conclusions. Li and Buckle (1999) add that with using this tool "it is difficult to justify the magnitude of 'risks' when the combination of several factors is presented within a job" (p. 676).

Table 2-40 PLIBEL checklist questions that relate to the LE (Kemmlert & Kilbom, 1987)

PLIBEL Checklist Question #	Related Checklist Question for Feet and Knee/Hip Body Regions
1	Is the walking surface uneven, sloping, slippery or nonresilient?
2	Is the space too limited for work movements or work materials?
3	Are tools and equipment unsuitably designed for the worker or the task?
6	(If the work is performed whilst standing): Is there no possibility to sit and rest?
7	Is fatiguing foot-pedal work performed?
8	Is fatiguing leg work performed e.g.:
8a	Repeated stepping up on stool, step etc.?
8b	Repeated jumps, prolonged squatting or kneeling?
8c	One leg being used more often in supporting the body?

Foreman's et al. Method – 1988

Foreman et al. (1988) developed a method to identify frequencies and durations for postures and activities. This model was originally tested for nurses in the health industry using video and computer software. Practitioners analyze the task either through real-time observation or video analysis and record the changes in posture or activity to the computer. This differs from the standard method of recording observations every 3 seconds due to the observer only recording when there is a noted change in posture or activity.

Another difference in this method from the other posture assessment tools is that instead of categorizing by individual body regions, it looks at the body as a whole. Eight categories of postures and activities are available to be chosen from by the user. These are 1) standing, 2) sitting, 3) stooping, 4) forward leaning, 5) squatting, 6) kneeling, 7) walking, and 8) miscellaneous. Each of these categories has a further derivation into sub-categories such as offload, twist, reach (unilateral/bilateral), lift, hold, push, pull, etc. The system user inputs mnemonic codes in reference to the posture or activity that they are currently observing. From the results of the frequencies and durations of each posture and activity, experienced subjective judgment is used to deduce risk from a task.

Leonard & Keyserling – Posture Identification System – 1989

Based on previous research to develop a real-time computer-aided analysis system for the trunk and shoulders (Keyserling, 1986), Leonard and Keyserling (1989) further contributed to the study by accommodating the neck and lower extremities. It is similar to Foreman's et al. (1988) method and OWAS (Karhu et al., 1977), in that its objective is to identify postures and activities. The intention of this tool is to identify and associate the listed postures and activities for both legs (when referencing the LE) to their particular tasks for a job or company. It does not however, offer detailed analysis or action changes for tasks. Eight postures were recognized to affect the LE (Table 2-40). These identified postures were based on posture and activities rather than just body positions due to the deficiency of prior research available on the subject.

Table 2-41 Eight postures and activities for lower extremity regions (Leonard & Keyserling, 1989)

Posture / Activity	Additional Information
Walk	Body weight is supported by feet alone
Stand	Body weight unsupported by an external object
Lean	Body weight partially supported by an external object during a standing posture
Squat	Knee flexion angle of 90-180°
Deep squat	Knee flexion angle < 90°
Kneel	Majority or part of the body weight being supported by knee(s) contacting a surface
Sit	Majority of body weight being supported by buttocks and feet are supported by floor or footrest
No support	Not supported by anything other than the lower extremity joint or segment itself (e.g., laying down or legs hanging)

Gil & Tunes' Method – 1989

A tool for full body postural assessment was designed specifically for sitting tasks (Gil & Tunes, 1989). This model allows static postural recording of body positions. Body regions accounted for in the model include the head and trunk areas unilaterally, and arms, thighs, knees, ankles and feet bilaterally. Consideration was given to crossed legs (such as at the knees or ankles). Also taken into account are areas that could be supported while sitting (such as the arms, feet, and back). Angles between body segments are also capable of being recording in 15° approximations. The angular creating segments of the body to be measured comprise of the thigh-leg, thigh-trunk, and trunk-arm relations. Each postural assessment card allows four different activities to be evaluated.

Gil and Tunes (1989) reveal that this model is useful for static postures where ample time is given (approximately 43 s) to record the activity. In situations not allowing the time necessary, use of video recording and playback would be required. This method would be useful when creating a dynamic flow of activities through a time-sampling technique. In addition, Gil and Tunes (1989) mention that a thorough comprehension of postures' affects on the musculoskeletal system of the body would require the use of supplementary factors such as "…physiological indicators, biomechanics analysis, subjective methods for identifying discomfort and fatigue, performance measures…" (p. 57).

Chen et al. – Physical Work Stress Index (PWSI) – 1989

The Physical Work Stress Index (PWSI) is another whole body analysis tool that identifies high static loading, low quantities of posture changes, and extreme dynamic loading (J. Chen, Peacock, & Schlegel, 1989). Additional detail is given to postural risk for this model. It is divided into location, orientation, left hand position, right hand position, and postural base. Chen et al. (1989) define postural base as the area of the body that supports the weight of the body (p. 169). In reference to the LE, postural bases include lying, sitting, leaning, and standing. Chen et al. (1989) mention that standing creates the highest need for muscle operation of the four postural bases offered. Thus, their concept is that increased muscle action will cause faster muscle fatigue. Therefore, as the area of body support decreases from lying to standing, each posture increases in risk rank from 1-4 accordingly.

In addition to these postural factors, are forces and load factors for upper extremity accelerations and external weights, as well as environment temperature. Each of these factors is given a weight as well by practitioners (ranking 1-4). These weights are summed by the tool's computer software to give total body risk as a PWSI number. High

PWSIs mean that the task observed has high dynamic work stresses whereas low PWSIs refer to highly static work stresses (Pinzke, 1997). Moreover, Pinzke (1997) says that polar coordinated graphs are given to visually describe the weights of each component in relation to each other (using sector angles) and their measured values (using radii). The reliability of this tool depends highly on the frequency of its sample collections for a task (J. Chen et al., 1989).

Keyserling et al. – Posture Checklist – 1992

A checklist was developed by Keyserling et al. (1992) to rapidly assess postural risks associated to the legs, trunk, and neck of the body (David, 2005). This checklist was originally used by management for automotive manufacturing and warehousing tasks (Keyserling et al., 1992). Keyserling et al. (1992) mention that many postures are coupled with pain or discomfort and approximately one-third of the industries that they reviewed had workers complaining of knee, lower leg, and foot discomforts from the awkward postures. It was concluded based on study, that five lower extremity postures would be used in the checklist as postural risks. They were; 1) standing stationary, 2) lying on back or side, 3) using foot pedal while standing, 4) kneeling, and 5) knees bent or squatting (knee flexion angle < 150°).

The checklist's postures are grouped under the three body sections of general body posture/legs, trunk posture, and neck posture. Each posture then has three categories for exposure duration of *never*, *sometimes*, and *greater than one –third* (Table 2-41). Qualitative stress rating responses for each of these categories can be given as *zero*, *check*, or *star* (Table 2-42). A total risk score for a task was quantified by adding the total number of checks with the total number of stars.

Table 2-42 Given categories for duration of exposure and their explanations (Keyserling et al., 1992)

Duration of exposure	Explanation
Never	The job involved no exposure to the particular posture
Sometimes	The posture was required to perform the job however, the total duration of the posture was less than one-third of the work cycle or work day
Greater than one-third	The posture was required to perform the job and the total duration was greater than one-third of the work cycle or work day

Table 2-43 Given responses for stress ratings and their explanations (Keyserling et al., 1992)

Stress rating response	Explanation
Zero	Using the posture for the indicated duration presented insignificant risk of injury or illness.
Check	Moderate exposure to postural stress was present, indicating a potential risk of injury to some workers.
Star	Substantial exposure to postural stress was present, indicating significant risk of injury.

Pitfalls noticed by Keyserling et al. (1992) regarded the use of the qualitative stress measures' symbols. Confusion developed in the initial validation experiments following the development of the tool due to users being unfamiliar with the system of zeroes, checks, and stars. Users also wanted the ability to associate risk factors to explicit tasks possibly by giving room on the checklist for additional notes.

Fransson-Hall et al. – Portable Ergonomic Observation (PEO) – 1995

A whole body analysis software tool was developed to investigate tasks by assessing the postures and manual handling methods used by the people that perform them (Fransson-Hall et al., 1995). This model is known as the Portable Ergonomic Observation Method (PEO). Observations are made and recorded in video format by the PEO software in a single dimension (sagittal perspective), then activity frequencies and durations are calculated, and final results are examined at a later time by subject matter experts. Fransson-Hall et al. (1995) believe that by using computers for real-time analysis of events and activities, accuracy about the sequences, frequencies, and durations will be increased.

Four body regions and manual handling criteria compose the categories observed by PEO. These body regions include the bilateral category of hands (left and right), and the unilateral categories of the neck, trunk, and knee (specifically kneeling or squatting). In addition, information entered pertaining to forces is collected separately by the practitioner through dynamometer (for push/pull forces) and scales readings (for weights) (Fransson-Hall et al., 1995).

Observation and analysis can be executed in two methods according to Fransson-Hall et al. (1995). The first is to carry out both objectives for all the body region and manual handling categories simultaneously for a holistic overview. The second is to choose and perform an assessment explicit to one body region or manual handling category. The intention of the latter method is to increase the sensitivity or accuracy of the tool's results to the specific need at hand.

In regards to the LE, the information collected about the knees themselves is related more to the inclusion of the kneeling or squatting activities and possibly durations and frequencies rather than the knee's angular postures and moments. Furthermore, Fransson-Hall et al. (1995) realized that there can be variations in real-time observational techniques such as missing information due to fast worker rate. This misinformation can lead to analysis error. They mention that this can be circumvented by the results of past research (van der Beek, A. J., van Gaalen, & Frings-Dresen, 1995) such as 1) using several observational occasions to observe different pieces of information at a time, 2) using two or more observers on the same occasion to record different pieces of information, or 3) using recorded video for subsequent analyses to achieve all of the necessary pieces of information.

McAtamney & Hignett – REBA – 1995

Rapid entire body assessment (REBA) is an existing tool that takes into account the multiple regions of the entire body (trunk, neck, legs, upper arms, lower arms, and wrists) (Hignett & McAtamney, 2000). Exposure factors included in REBA comprise individual posture, load/force requirements, movement frequency, and load coupling (David, 2005). Designed using jobs and tasks from the electrical and hospital industries (McAtamney & Hignett, 1995), Hignett and McAtamney (2000) mention that this tool was developed to work with the service environments, particularly to the health care environment where they mention that postures and material handling methods are indiscriminately carried out.

What is unique to the REBA tool is that it is one of the most recent tools to assimilate consideration for bilateral or unilateral weight bearing and stability for the legs, walking and sitting, as well as knee flexion. Greater risk quantity is given to tasks requiring more awkward postures or acute knee joint angles (> 60° knee flexion from vertical). In addition, REBA realizes that there is a risk difference to the musculoskeletal system for tasks that use postures of static, dynamic, or irresolute natures (McAtamney & Hignett, 1995). Similar in methodology to RULA (McAtamney & Corlett, 1993), REBA bases its postural scores on how the postures affect muscle groups and body biomechanics (McAtamney & Hignett, 1995). Results of calculated overall risk scores (1-15) are accompanied by associated risk level terms and action assessments (Table 2-43).

Table 2-44 REBA action levels, risk scores and action assessments (Hignett & McAtamney, 2000)

Action level	REBA score	Risk level	Action Assessment
0	1	Negligible	None necessary
1	2-3	Low	May be necessary
2	4-7	Medium	Necessary
3	8-10	High	Necessary soon
4	11-15	Very High	Necessary now

Graf's et al. Method – 1995

As noted by Chen et al. (1989), Graf et al. (1995) also view sedentary postures as a higher risk for WMSDs. Sitting tasks can therefore be deemed as sedentary in nature and thus, at risk for development of WMSDs to workers. It is therefore encouraged by the authors to include movement in postures that can be sedentary throughout a task or work period. Sitting postures for tasks are captured through a series of identified body region positions on a matrix throughout five workplace environments using observational and questionnaire (for discomfort identification) techniques. The workplace's jobs tested included assembly, office, listening, VDU (visual display units), and cashier tasks.

The body regions comprise of the shoulders, spinal curve, trunk, and legs. Of these regions, there are 68 positions to choose from with the leg region (relative to the thigh and torso angles and postures) having six choices. These postural positions for the legs included 1) knees raised, 2) knees raised and crossed, 3) thighs parallel to the floor, 4) knees lowered and crossed, 5) knees lowered, and 6) thighs in vertical. Postural recordings were done in intervals of one every minute for up to two hours of a task or work interlude. This information is then entered into the tools software for statistical analysis. Tool results were in the form of graphical printouts. These graphs displayed frequencies of the different postures as well as the frequency of postural change.

Summary

Of the tools and models reviewed (Table 2-40), two are considered as checklist tools that look at the work environment of the employee. These are PLIBEL (Kemmlert & Kilbom, 1987) and the Postural Checklist (Keyserling et al., 1992). Three tools stand apart as joint position assessments through angles of deviation rather than as postures such as standing or sitting. These are the Posturegram (Priel, 1974), Posture Targetting (Corlett et al., 1979), and Gil and Tune's (1989) method. A resulting observation of this review has also pointed out that postural assessment is currently the primary indicator of risk for not only the LE but the body as a whole. Though posture is considered a risk, other cofounders exist as well such as activities performed, activity frequencies and durations, vibration exposures, and forces exerted. Most of these tools detect categories relating to activities and forces/loads but few are capable of considering vibration or other risks. Regions of the LE are typically compounded into the category of lower extremity or lower limbs. When resources are extended to LE detail, the knee joint's flexion angle is the primary focus, which as explained beforehand in the postural discomforts section of this literature review, agitates areas of the legs and lower back depending on degree of flexion. Prolonged and repeated squatting has also been shown to develop into WMSDs for related occupations.

Data collection methods are typically performed through observation of tasks with a few including self-reports and direct measure. 10 out of 13 of the tools are capable of being used for both static and dynamic movement tasks using either time-sampling or real-time video captures. PLIBEL (Kemmlert & Kilbom, 1987) is the only model that offered an initial start point for mitigation strategies. Risk quantification is the last category summarized in Table 2-44. This critical category acknowledges that a risk is present and is either negligible or needs review. Five out of the 13 reviewed tools are capable of summarizing risk into a format that shows interpretation of the quantity. These tools are; OWAS (Karhu et al., 1977), ARBAN (Holzmann, 1982), PWSI (J. Chen et al., 1989), the Postural Checklist (Keyserling et al., 1992), and REBA (McAtamney & Hignett, 1995).

Table 2-45 Overview of risk assessment models and tools

		Tool and Model Review Category						
Model	**Source**	**Model Description**	**Accounted LE Regions**	**Accounted LE Risk Factors**	**Data Collection Method**	**Preferred for Static or Dynamic Activity Assessment**	**Possible Mitigations Offered?**	**Is Risk Quantified?**
The Posturegram	Priel, 1974	Static 3D whole body postural assessment tool. Limb angles measured in 15° approximations.	Hips, Knees, Ankles, Thighs, Lower legs, Feet	Posture	Observational	Static	No	No
OWAS	Karhu et al., 1977	Whole body postural assessment tool. Assessed as both limb position and activity.	LE as a whole rather than individual parts	Posture, Activity type, Load/force	Observational, Direct measurement	Both – (Dynamic using time-sampling)	No	Yes (into operative classes)
Posture Targetting	Corlett et al., 1979	Whole body assessment tool. Assesses position and direction of limbs and joints as well as their activities.	Upper legs, Lower legs	Posture, Activity type	Observational	Both – (Dynamic using time-sampling)	No	No
ARBAN	Holzmann, 1982	Whole body assessment tool comparing risks to time intervals of a task using Borg's (1985) RPE scale.	LE as a whole	Posture, Load/Force, Vibration, Perceived exertion effort	Observational	Both – (Dynamic using time-sampling)	No	Yes (graphically)

		Tool and Model Review Category						
Model	**Source**	**Model Description**	**Accounted LE Regions**	**Accounted LE Risk Factors**	**Data Collection Method**	**Preferred for Static or Dynamic Activity Assessment**	**Possible Mitigations Offered?**	**Is Risk Quantified?**
PLIBEL	Kemmlert & Kilbom, 1987	Whole body risk identification checklist.	Hips, Knees, Feet	Activity type, Activity frequency, Environment walking surface, Environment work space, Tool design	Self-report, Observational	Both – (based on task activity instead of posture)	Yes	No
Foreman's et al. Method	Foreman et al., 1988	Whole body task analysis giving frequency and duration to activity and posture as results.	LE as a whole	Posture, Activity type	Observational	Both – (Dynamic using real-time)	No	No
Posture Identification Method	Leonard & Keyserling, 1989	Identifies the postures and activities performed for a task for the whole body.	LE as a whole. Knee flexion angle is indicated for kneeling and squatting.	Posture, Activity type	Observational, Direct measurement (for knee angles)	Both – (Dynamic using real-time)	No	No
Gil & Tune's Method	Gil & Tunes, 1989	Postural assessment model used for sitting activities.	Thighs, Knees, Lower legs, Ankles	Posture, Activity frequency	Observational	Both – (Dynamic using time-sampling)	No	No

		Tool and Model Review Category						
Model	**Source**	**Model Description**	**Accounted LE Regions**	**Accounted LE Risk Factors**	**Data Collection Method**	**Preferred for Static or Dynamic Activity Assessment**	**Possible Mitigations Offered?**	**Is Risk Quantified?**
PWSI	J. Chen et al., 1989	Whole body assessment tool.	LE as a whole	Posture, Load/Force, Vibration, Environmental temperature	Observational	Both – (Dynamic using time-sampling)	No	Yes
Postural Checklist	Keyserling et al., 1992	Checklist that identifies risks related to task postures. Designed as an initial risk screening tool for tasks.	LE as a whole. Knee flexion angle is indicated for kneeling and squatting.	Posture, Activity type, Activity duration	Observational, Direct measurement (for knee angles)	Static	No	Yes
PEO	Fransson-Hall et al., 1995	Real-time analysis software using recorded video.	Knees	Posture, Activity frequency, Activity duration, Activity sequence, Load/force	Self-report, Observational, Direct measurement	Both – (Dynamic using real-time)	No	No

		Tool and Model Review Category						
Model	**Source**	**Model Description**	**Accounted LE Regions**	**Accounted LE Risk Factors**	**Data Collection Method**	**Preferred for Static or Dynamic Activity Assessment**	**Possible Mitigations Offered?**	**Is Risk Quantified?**
REBA	McAtamney & Hignett, 1995	A whole body assessment tool used to identify task risks	LE as a whole. Knee flexion angle is indicated for kneeling and squatting.	Posture, Load/force, Activity type, Activity frequency	Observational	Both – (Dynamic using time-sampling)	No	Yes
Graf's et al. Sitting Model	Graf, Guggenbuhl, & Krueger, 1995	Whole body assessment tool oriented for sitting postures and activities.	LE as a whole. Thigh-torso relationship is primarily inspected.	Posture	Self-report, Observational	Static	No	No

Literature Review Conclusion

This review contains information on a multidisciplinary level. It is the hope that the end result of this review will bring to light the concerns of LE WMSDs and discomforts for working industries. The objective of this review was to identify the path of a LE WMSD from the initial incident reporting level all the way to the causal risk factors. This methodology can be seen throughout the presentation of information within this literature review chapter. Continuing from national incident reports, detail is given about specific WMSDs that studies have verified to be prevalent to the LE. In addition, discomforts for the LE have been added, as sometimes the symptoms of damage detection of a WMSD may initially be imperceptible and instead coincide with the symptoms of discomfort. Aggregating the common risk variables noticed between LE WMSDs and discomforts can allow an investigation to begin evolving from a level of coincidence and inference to an established statistical relationship. This overview is previously mentioned in the WMSD Risk Variables section of this chapter. In the end, a review of past and current models and tools established to detect risks is summarized. This comparison and contrast method shows what risks are considered and what risks are not (Tables 2-45 and 2-46). They are intended to display the relationships and gaps between the current methods available and the prevalent risks assessed.

The current selection of tools available to assess LE risks has focused their efforts on occupational postures and activities. In particular, standing, imbalanced and/or leaning, chair sitting, knee flexion or squatting, and kneeling have been the obvious customary postural risks, while walking, pushing, and pulling are noticed to be the topics most often covered for activity risks. Rare postural risks (detected by one to two tools) touched on include leg crossing (only covered by Graf's et al. method), stooping (detected by Foreman's et al. method), and lying down (Posture Identification method, PWSI, and Postural Checklist). Rare activity risks included lifting (Foreman's et al. method and PEO), lowering (PEO), stair climbing (PLIBEL), and only one tool considered vibrations as a risk (ARBAN). What remains as obvious undetected gaps for postures, are the areas of tip-toeing, floor sitting, and tissue compression (through work surface leaning or equipment operation). Stacking and ramp climbing are undetected for activities.

A major resource left out of the assessment of these tools is that of personal risks. Although not considered as variables for postural discomforts, they can be chief contenders or cofounders in many of the WMSDs encountered for the LE. In addition to these undetected risks, are the risks that accompany personal protective equipment (PPEs) such as constrictive knee pads or weighty utility belts (see Nerve Entrapments under LE WMSDs). These risks should be considered at the minimum as concerns to the individual worker, especially when combined with the occupational risks they face at work. The job participation, health, and well-being of the LE should no longer be avoided by practitioners as acceptable risks of trade. A model needs to be developed to at the least, detect and quantify LE risk levels associated to a job or task.

Table 2-46 Occupational postural risks detected by reviewed tools and models

		Occupational Postural Risks											
Model or Tool	**Source**	Standing	Tip-Toeing	Imbalanced Standing or Leaning	Floor Sitting	Chair Sitting	Leg Crossing (while sitting)	Stooping	Knee Flexion or Crouching or Squatting	Kneeling	Lying Down	Tissue Compression On or Against Work Surface	Joint Positioning
The Posturegram	Priel, 1974												X
OWAS	Karhu et al., 1977	X		X		X			X	X			
Posture Targetting	Corlett et al., 1979												X
ARBAN	Holzmann, 1982												
PLIBEL	Kemmlert & Kilbom, 1987	X		X					X	X			
Foreman's et al. Method	Foreman et al., 1988	X		X		X		X	X	X			
Posture Identification Method	Leonard & Keyserling, 1989	X		X		X			X	X	X		
Gil & Tune's Method	Gil & Tunes, 1989												X
PWSI	J. Chen et al., 1989	X		X		X					X		
Postural Checklist	Keyserling et al., 1992	X							X	X	X		
PEO	Fransson-Hall et al., 1995								X	X			
REBA	McAtamney & Hignett, 1995	X		X		X			X				
Graf's et al. Sitting Model	Graf et al., 1995					X	X						

Table 2-47 Occupational activity risks detected by reviewed tools and models

		Occupational Activity Risks									
Model or Tool	**Source**	Walking	Pushing	Pulling	Lifting	Lowering	Stacking	Stair Climbing	Ramp Climbing	Hand-Arm Tool Vibration	Work Surface Vibration
The Posturegram	Priel, 1974										
OWAS	Karhu et al., 1977	X									
Posture Targetting	Corlett et al., 1979	X	X	X							
ARBAN	Holzmann, 1982									X	
PLIBEL	Kemmlert & Kilbom, 1987							X			
Foreman's et al. Method	Foreman et al., 1988	X	X	X	X						
Posture Identification Method	Leonard & Keyserling, 1989	X									
Gil & Tune's Method	Gil & Tunes, 1989										
PWSI	J. Chen et al., 1989										
Postural Checklist	Keyserling et al., 1992										
PEO	Fransson-Hall et al., 1995		X	X	X	X					
REBA	McAtamney & Hignett, 1995	X									
Graf's et al. Sitting Model	Graf et al., 1995										

CHAPTER THREE : METHODOLOGY

Objective of Dissertation Research

This study was approved by the University of Central Florida's Institutional Review Board (IRB). The Musculoskeletal Disorder (MSD) Causation model was developed to better understand the relationships between various risk factors and resulting physical traumas to the lower back and upper extremities (National Research Council, 1999; National Research Council, 2001). The results of these studies were formatted into a conceptual relationship model (Figure 3.1). The model's risk factors are very similar to those found in the lower extremity (LE) research from Chapter Two's literature review. The weight of workplace influence is derived from external loads, organizational factors, and social context. Individual factors, although not workplace related, are considered as a fourth group of risks that influence a person's well-being. These four risk groups influence the physiological pathways, meaning that all four affect biomechanical loading (internal loads and physiological responses) which directly affects the outcomes of discomfort and disorder through internal tolerances. Individual factors affect internal tolerances (mechanical strain and fatigue) as well.

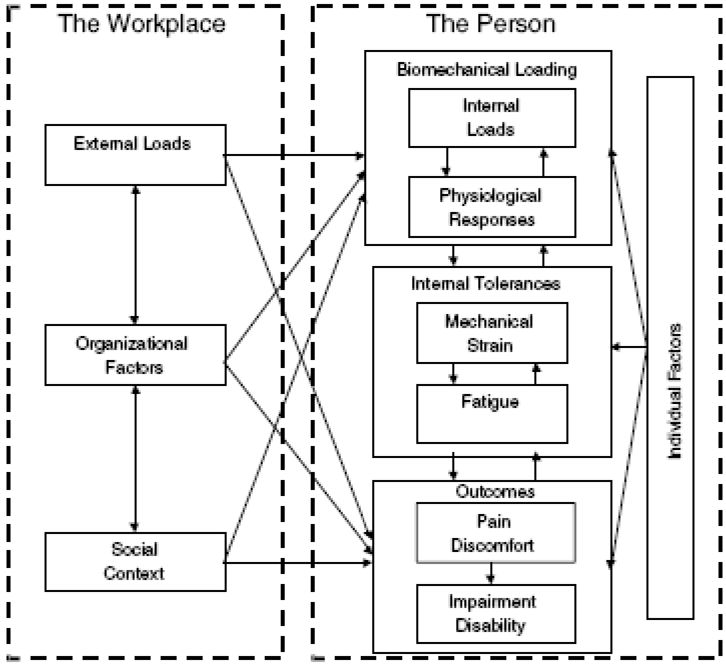

Figure 3.1 Conceptual model of MSD causation to discomforts and disabilities. Reprinted with permission from Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities, 2001 by the National Academy of Sciences, Courtesy of the National Academies Press, Washington, D.C.

So how is this information relative to LE occupational risk? Obviously the lower extremity, when used to assume postures and activities incorporate each of the sub-systems of the musculoskeletal system (skeletal, muscular, nervous, and vascular). An overview of the results of this work performed by the National Research Council (1999) shows the following variables as risk factors:

- External Loads
  - Work Procedures
  - Equipment
  - Environment
- Organizational Factors
- Social Context
- Individual Factors

- Physical
- Psychological

The NRC's risk variables suggest that occupational and personal risks collected from Chapter Two are valid. With the exclusion of organizational and social context factors, the external loads and individual factors are the only risk groups adopted into this LE risk model. With the main risk categories understood, attention of this methodology now focuses on requirements for experimentation and data collection.

The primary objective of this dissertation research as mentioned in Chapter 1,was *the quantification of occupational and personal risk variables into a set of equations that would approximate the total risk to a worker's LE regions during a job or task*. Due to time constraints, I have reduced the risk tool to assessing only tasks for disorders related to the knee. Therefore, the remainder of this dissertation will focus on this well documented joint with the expectation that it can be modeled for occupationally related risk. It should also then be possible to model the rest of the LE whether holistically or regionally. The remainder of this chapter is dedicated to this research design, with clear descriptions of risk guidelines, participants, data collection variables, and experimental design.

Knee Disorder Risk Guideline & Data Collection

Based on information gathered in Chapter Two's WMSD and discomfort sections, we can begin formalizing the epidemiology of the knee into noticeable patterns. Initially the results can be used to establish a set of risk guidelines (Tables 3-1 – 3-5). From these we can begin to look beyond just variable association and illuminate the types of units used and their threshold quantities. In their generic form we can also see how these risks, whether in single or multi-variant form, may lead to a possible disorder (knee bending and physical workload, for example). Starting with the relationship between postural activity and knee discomfort, we can show that the same risk variables of kneeling and squatting also result in discomfort (Table 3-1). These same risks of kneeling and squatting are reiterated throughout all three LE WMSDs. Of the disorders considered to be occupationally susceptible, knee bursitis is considered to have the least guideline information available in the literature; the only exception involves risk relating to carpet installation knee kicker tools (see discussion of WISHA recommendation in Chapter Four's Final Model Results). A review of the meniscal disorder literature reveals only the study of Baker et al. (2003) (Table 3-5). The largest data set by far, concerns osteoarthritis (OA) of the knee, which produced numerous citations of the same risks for occupational variables (Table 3-2). Knee OA is also the only disorder to show a link between personal factors (such as past injury or age) and the resulting disorder (Table 3-3). Table 3-4 displays the only available information from knee epidemiological literature showing an interaction of personal risk factors with occupational factors (kneeling and/or squatting).

Table 3-1 Postural activity discomforts and the knee joint

Posture or Activity	Exposure Quantity	Statistical Measure	Source
Chair sitting (while driving)	> 6 hrs / work day	(OR = 2.52, 95% CI: 1.36,4.65)	Chen et al., 2001
Chair sitting (while driving)	6-8 / work day	(OR = 1.99, 95% CI: 1.00,3.98)	Chen et al., 2001
Chair sitting (while driving)	8-10 / work day	(OR = 2.55, 95% CI: 1.32,4.94)	Chen et al., 2001
Chair sitting (while driving)	>10 / work day	(OR = 3.14, 95% CI: 1.62,6.08)	Chen et al., 2001
Kneeling (men)	>1 hr / work day	NA	Baker et al., 2003
Squatting (men)	>1 hr / work day	NA	Baker et al., 2003

OR = Odds Ratio; CI = Confidence Interval; NA = Not Applicable

Table 3-2 Occupational risks and knee OA

Occupational Risk Type	Posture or Activity	Exposure Quantity	Statistical Measure	Source
Posture	Squatting	> 30 mins / work day	(OR = 6.9, 95% CI: 1.8,26.4)	Cooper et al., 1994
	Squatting	> 1 hr / work day	(OR = 2.3, 95% CI: 1.3,4.1)	Coggon et al., 2000
	Kneeling	> 30 mins / work day	(OR = 3.4, 95% CI: 1.3,9.1)	Cooper et al., 1994
	Kneeling	> 1 hr / work day	(OR = 1.8, 95% CI: 1.2,2.6)	Coggon et al., 2000
	Kneeling or squatting	> 2 hr / work day	(OR = 1.73, 95% CI: 1.13,2.66)	Manninen et al., 2002
Activity	Stair climbing	> 10 flights / work day	(OR = 2.7, 95% CI: 1.2,6.1)	Cooper et al., 1994
	Stair climbing (men)	≥ 15 flights / work day	(OR = 2.5, 95% CI: 1.0,6.4)	Lau et al., 2000
	Stair climbing (women)	≥ 15 flights / work day	(OR = 5.1, 95% CI: 2.5,10.2)	Lau et al., 2000
	Stair/Ladder climbing	> 30 flights / work day	(OR = 1.5, 95% CI: 1.0,2.3)	Coggon et al., 2000
	Lifting ≥ 22 lbs (men)	≥ 10 times / work week	(OR = 5.4, 95% CI: 2.4,12.4)	Lau et al., 2000
	Lifting ≥ 22 lbs (women)	≥ 10 times / work week	(OR = 2.0, 95% CI: 1.2,3.1)	Lau et al., 2000
	Lifting ≥ 55 lbs	> 10 times / work week	(OR = 1.7, 95% CI: 1.2,2.6)	Coggon et al., 2000
	Lifting ≥ 110 lbs	> 10 times / work week	(OR = 1.4, 95% CI: 0.9,2.2)	Coggon et al., 2000
	Lifting/carrying (women)	≥ 25-50 lbs / item	(OR = 2.53, 95% CI: 0.82,7.85)	Felson et al., 1991
	Heavy lifting combined with kneeling, squatting, or stair climbing	> 55 lbs / item	(OR = 5.4, 95% CI: 1.4,21.0)	Cooper et al., 1994
	Lifting/carrying combined with kneeling, squatting, crouching or crawling (men)	≥ 25-50 lbs / item	(OR = 2.22, 95% CI: 1.38,3.58)	Felson et al., 1991
	Heavy lifting combined with kneeling or squatting	> 55 lbs / item	(OR = 3.0, 95% CI: 1.7,5.4)	Coggon et al., 2000
	Walking	> 2 miles / work day	(OR = 1.9, 95% CI: 1.4,2.8)	Coggon et al., 2000
Tool Usage	Vibration tools (men)	> 1 hr / work day	(OR = 2.8, 95% CI: 0.8,10.0)	Lau et al., 2000
	Vibration tools (women)	> 1 hr / work day	(OR = 3.7, 95% CI: 0.7,20.1)	Lau et al., 2000

OR = Odds Ratio; CI = Confidence Interval; NA = Not Applicable

Table 3-3 Personal risks and knee OA

Personal Risk Type	Personal Risk	Statistical Measure	Source
Injury History	Past injury or surgery (men)	(OR = 12.1, 95% CI: 3.4,42.5)	Lau et al., 2000
	Past injury or surgery (women)	(OR = 7.6, 95% CI: 3.8,15.2)	Lau et al., 2000
Body Mass Index (Overweight)	BMI > 25.3	(OR = 3.6, 95% CI: 1.7,7.5)	Cooper et al., 1994
	BMI 25 – 29.9 (men)	(OR = 1.69, 95% CI: 1.03,2.80)	Anderson & Felson, 1988
	BMI 25 – 29.9 (women)	(OR = 1.89, 95% CI: 1.24,2.87)	Anderson & Felson, 1988
Body Mass Index (Obese)	BMI 30 - 35 (men)	(OR = 4.78, 95% CI: 2.77,8.27)	Anderson & Felson, 1988
	BMI 30 - 35 (women)	(OR = 3.87, 95% CI: 2.63,5.68)	Anderson & Felson, 1988
Body Mass Index (Very Obese)	BMI > 35 (men)	(OR = 4.45, 95% CI: 1.77,11.18)	Anderson & Felson, 1988
	BMI > 35 (women)	(OR = 7.37, 95% CI: 5.15,10.53)	Anderson & Felson, 1988

OR = Odds Ratio; CI = Confidence Interval; NA = Not Applicable

Table 3-4 Combinational risk of kneeling/squatting with age, injury history and BMI scores for knee OA

Personal Risk Type	Personal Risk	Statistical Measure	Source
Age	Age 45-54 (women)	(OR = 2.07, 95% CI: 0.71,6.08)	Anderson & Felson, 1988
	Age ≥ 55-64 (men)	(OR = 2.45, 95% CI: 1.21,4.97)	Anderson & Felson, 1988
	Age ≥ 55-64 (women)	(OR = 3.49, 95% CI: 1.22,10.52)	Anderson & Felson, 1988
Injury History	Past Injury or surgery	(OR = 7.6, 95% CI: 2.1,26.9)	Cooper et al., 1994
Body Mass Index (Normal weight)	BMI < 25	(OR = 2.2, 95% CI: 1.1,4.5)	Coggon et al., 2000
Body Mass Index (Overweight)	BMI 25 – 29.9	(OR = 6.1, 95% CI: 3.4,10.9)	Coggon et al., 2000
Body Mass Index (Obese)	BMI ≥ 30	(OR = 14.7, 95% CI: 7.2,30.2)	Coggon et al., 2000

OR = Odds Ratio; CI = Confidence Interval; NA = Not Applicable

Table 3-5 Occupational risks and knee meniscal disorders

Occupational Risk Type	Posture or Activity	Exposure Quantity	Statistical Measure	Source
Posture	Squatting	> 1 hr / work day	(OR = 1.8, 95% CI: 1.1,3.0)	Baker et al., 2002
	Squatting (men)	> 1 hr / work day	(OR = 2.5, 95% CI: 1.2,4.9)	Baker et al., 2003
	Kneeling	> 1 hr / work day	(OR = 2.2, 95% CI: 1.3,3.6)	Baker et al., 2002
	Kneeling (men)	> 1 hr / work day	(OR = 2.5, 95% CI: 1.3,4.8)	Baker et al., 2003
	Chair sitting (while driving)	> 4 hrs / work day	(OR = 2.3, 95% CI: 1.4,4.0)	Baker et al., 2002
Activity	Standing up from kneel or squat position	> 30 times / work day	(OR = 1.9, 95% CI: 1.2,3.1)	Baker et al., 2002
	Standing up from kneel or squat position (men)	> 30 times / work day	(OR = 1.9, 95% CI: 1.0,3.8)	Baker et al., 2003
	Stair climbing	> 30 flights / work day	(OR = 2.4, 95% CI: 1.6,3.8)	Baker et al., 2002
	Stair climbing (men)	> 30 flights / work day	(OR = 2.0, 95% CI: 1.0,4.1)	Baker et al., 2003
	Standing (men)	> 2 hrs / work day	(OR = 1.5, 95% CI: 0.8,3.1)	Baker et al., 2003
	Walking	> 2 miles / work day	(OR = 1.5, 95% CI: 0.9,2.3)	Baker et al., 2002
	Walking (men)	> 2 hrs / work day	(OR = 1.5, 95% CI: 0.8,3.1)	Baker et al., 2003
	Lifting or moving heavy items (men)	> 22 lbs / item	(OR = 1.7, 95% CI: 0.9,3.1)	Baker et al., 2003
	Lifting items ≥ 22 lbs	> 10 times / work week	(OR = 1.9, 95% CI: 1.2,2.9)	Baker et al., 2002
	Lifting items ≥ 55 lbs	> 10 times / work week	(OR = 1.7, 95% CI: 1.1,2.7)	Baker et al., 2002
	Lifting items ≥ 110 lbs	> 10 times / work week	(OR = 2.4, 95% CI: 1.4,4.2)	Baker et al., 2002

OR = Odds Ratio; CI = Confidence Interval; NA = Not Applicable

Data Collection

From the knee disorder epidemiology guidelines we derived the variables that were collected during the research stages (Table 3-6). Also included in this table are the quantification methods (such as time or load) that are known to associate to a knee disorder. Personal risks, such as knee incident history (excluding dermal incidents), height, weight, knee related habits/hobbies, and age was captured through an administered questionnaire. BMI was calculated using a person's weight (pounds) divided by the squared value of their height (in) whose quotient is then multiplied by 703 (Center for Disease Control, 2007). These data were developed into spreadsheet which was shown to workers so that they could easily find their approximate BMI score (Appendix C's BMI Score Chart). This gave a better overall view of total work day exposures and plausible risks for individuals. The remaining variables were captured through observation of postural activities and direct measure of physical work loads. Both left and right extremities were observed and evaluated individually during knee contact postures or activities. Observational data capture was aided with the use of video taping tasks for post-observational assessment. Additional information was also gathered during the video observation stage such as task duration and total exposure counts per postural activity. Total variable collection was for the original 16 risk variables gathered from the literature. Of these, 4 were personally related. Discomfort from prolonged sitting was not considered as part of the research since this study's focus is on morbidity.

Table 3-6 Data collection variables and associated disorders

Risk Variables	Metric Used	Occupational Risk	Personal Risk	OA	Meniscal Disorder	Knee Bursitis	Knee Discomfort
Kneeling	Counts per day; Minutes/hours per 8 hr day	X		X	X	X	X
Squatting or crouching	Counts per day; Minutes/hours per 8 hr day	X		X	X		X
Crawling	Counts per day; Minutes/hours per 8 hr day	X		X	X		
Stair/ladder climbing	Flights climbed per 8 hr day	X		X	X		
Lifting/carrying	Counts per day; pounds per item	X		X	X		
Walking	Hours per 8 hr day;	X		X	X		
Standing	Hours per 8 hr day	X			X		
Standing up from a kneel or squat position	Counts per day	X			X		
Chair sitting (while driving)	Hours per 8 hr day				X		X
BMI	BMI score		X	X			
Height	Inches (in)		X	NA	NA	NA	NA
Weight	Pounds (lbs)		X	NA	NA	NA	NA
Past knee injury/surgery	Yes/No		X	X			
Age	Years		X	X			
Vibrating tools	Hours per 8 hr day	X		X			
Using the knee as a hammer	Yes/No	X				X	
Prolonged contact stress against the patella bone while standing	Yes/No	X				X	
Physically intensive habits/hobbies that could affect the knee	Yes/No; counts per week		X		X		

NA = Not Applicable

Of these 16 variables, all were considered variables independent of each other. Variable interaction was considered on a limited basis. For example, studies of a combination of variables such as obesity with kneeling or heavy carrying while stair climbing have shown a risk association (Coggon et al., 2000; Cooper et al., 1994; Felson et al., 1991). Initial sample site incident data and task observations revealed that these risk factors were noticed in work areas that had knee morbidity cases in the past. Examples of postural activity noticed included static standing, kneeling, and squatting as well as climbing up and down ramps, stairs, and ladders. Contact stresses are noted to occur along aircraft work surfaces when workers needed added postural stability. Time durations of both the tasks themselves and for each exposure period per risk variable were also gathered.

Aside from the data collection during the observation periods, data collection from subject matter experts was also required. This was done in two stages of the research, which will be further detailed later in this chapter. The first was during the Model Development stage where 7 subject matter experts assessed the relationships of the independent risk variables with morbidity outcomes. The subject matter experts also helped resolve the final stages of the model's development process by determining the exposure weights for each of the variables. Additionally, they also looked at the "multiplier" factor for each risk variable's exposure thresholds. It was necessary for these thresholds to be resolved so that qualifiers could be attached to them such as "No exposure" or "Low/ Moderate/High" exposures.

The final group of subject matter experts was chosen from the sample site's group of professional senior ergonomists. Their purpose was to decide objectively and individually on the hazard level of a task (whether there was a task-related knee risk association or not). If these individuals deemed the task to be positively associated, then they also gave additional information which referred to which knee (if not both knees) may be at risk. This was carried out for all 17 of the assessed observations. This data collection was used for validating against the risk scores seen from the model's occupational risk assessment.

Participants

Participants for this research were divided amongst 3 groups. The first group was the Model Development group that helped in formalizing the algorithms noted in the Model Development section following this section. This group was made of up subject matter experts that specialized in the risks and disorders of the lower extremity typically seen in industrial environments. Examples of occupational titles in this group were industrial hygienists, physiologists, industrial athletic trainers, and ergonomists. The number of participants for this group was 7. Following the Model Development stage, the Hazard Analysis stage required another separate group of subject matter experts. This group of 3 specialized in industrial ergonomics and in particular, was experienced in the general nuances of aircraft assembly and manufacturing ergonomics. It was necessary to eliminate bias from this group as their objectivity of the task was key for later on during the Lower Extremity Risk Assessment (LERA) validation stage. Therefore, they were also chosen because they were not directly affiliated with the processes and people of the particular tasks chosen.

The last group of participants was chosen from the working population at a US aircraft manufacturer's aerospace assembly plant which was also the location of the sample site plant location. Nine full-time employees (male) aged 30 to 50 years old had careers in the company as aerospace mechanics and worked on assembling portions of the type of aircraft chosen. Although, the types of job titles that have been related to knee disorders through the sample site's incident reporting system (IRS) database included assemblers, sealers, mechanics, tool makers, crane operators, plumbers, electricians, and test technicians, only mechanical and electrical employees involved in this research. These employees were selected because they worked on tasks in areas where knee incident rates were high. Aside from these, there are no other specific constraints or concerns for participant selection.

Research Environment

In coordination with the manufacturer, incident and injury data were gathered from their safety and incident reporting systems. Due to the consistent evolution of manufacturing and assembly processes throughout the manufacturer's locations, a time constraint of only the year 2005 (January 2005 – December 2005) was added to the database query as these area's task processes had remained consistent during that time. Demographic constraints were limited to only one site location which dealt primarily with major aircraft assembly. From these, an additional refinement was completed to reveal work locations in factories that affected only the knees. Results of the search revealed job tasks that were associated with low work areas such as floor wiring and interior installation phases of the assembly process. Also at risk were tasks that involved prolonged standing and stair climbing, with or without a load, to locations inside or outside the body of the aircraft. It should also be noted that these types of jobs were on a 3 - 4 day cycle, meaning that they were not performed by employees on a daily basis. It is known though conversations with work area supervisors and employees themselves though, that similar types of tasks are performed by employees working in these job locations each day. This leads to similar risk exposures each work day.

Equipment & Tools

Equipment and tools were required to assess the participants and their environment. Photograph and video cameras were used to capture the work environment of the tasks as well as the postures and activities of the participants in them. They were used to view and assess the work environment at a later time during the model assessment processes. Weight scales were used to capture weights that participants picked up or carried during a working activity. Time stamps from the video observation stages captured durations and counts both for total task observation and individual risk exposures through the use of spreadsheets.

Task Sampling

The nature of this research was to test the feasibility in designing a tool that can detect and quantify risks to the knee. Similar to the Strain Index tool (Moore and Garg, 1995), this knee risk tool was created by incorporating the past knowledge and experiences found from practitioners (subject matter experts) and empirical evidence (past studies of epidemiology). Establishing a sample size with a given confidence in this type of research was difficult. Normally when independent and dependent variables are established and their relationship levels identified, then the sample size can be calculated. For the circumstances of this research, the independent variables were the risk factors and the dependent variables were the morbidity results of knee OA, meniscal disorders, and bursitis. These dependent variables cannot be ethically instigated and because their development is subjective to individuals and industries, sample size (the number of observations) for this research was not calculated.

Instead, past research methods from other studies were considered. The Strain Index was initially validated by contrasting its model's results against their sample site's exposure assessments of 32 jobs. Of these jobs, 14 were deemed as "hazardous" or "positive" through subject matter expert opinion (the rest were considered "safe"). Numerous jobs in aircraft assembly are exposed to the list of risk variables noted in previous sections of this study. Therefore, performing a site-wide risk analysis would have been extremely time-consuming (years) and well beyond the scope of allotted time for this dissertation research. Thus, following past foundations and our time constraints, only 15 initial tasks were selected to be used based on the preliminary incident rate data from the general task area locations and site advice from ergonomics and safety personnel. From these 15 tasks, 17 observations were made (due to a few of the participants performing the same type of task). These tasks included processes that were known to not only directly involve knee bending tasks alone, but also contained durations of standing or walking. This job risk variation helped develop the sensitivity (those people considered at risk by the tool when exposed to risk) and specificity (those considered safe by the tool when not exposed to risk) of the tool later on in the model by adjusting for false positives (Moore and Garg, 1995).

Model Development

The next step after guidelines and job/task assessment was to develop an initial model. This alpha version of the knee portion of the LERA model integrated information gathered from epidemiological literature, subject matter expert interviews, and surveys. Model development required two separate subject matter expert contributions. These were the model weight and model multiplier sections (see Appendix C's Model Development section for questionnaire examples). Once weights and multipliers were chosen for each risk factor, then they had the ability to form a risk factor resultant score (product). Adding these scores together produces either a task *occupational resultant score* or a *personal resultant score* (total names depend on which category is being tabulated). Occupational resultant scores for all observed task risks can be accumulated into a total occupational resultant score to produce a day's worth of risk to an individual. Note though that this type of calculation is solely based on the amount data input by an observer and will not account for risk outside of this. So if less than a day's worth of work is captured then the model will account for less than a day's worth of risk.

An example of a risk assessment model with a similar methodology although not developed for the lower extremity, was one developed in the studies by McCauley-Bell and Badiru (1996) and McCauley-Bell and Crumpton (1997). The objective of their research was to develop a predictive model that would assess risk to the worker's upper extremity's susceptibility to developing carpal tunnel syndrome (CTS). Their model was developed using fuzzy logic systems and analytical hierarchy process (AHP) tools. The results of their model arranged factors into three groups; personal, task (job), and environmental (organizational) (Table 3-7).

Table 3-7 Task, personal, and organizational risk factor groups and their sub-factors (McCauley-Bell & Badiru, 1996; McCauley-Bell & Crumpton, 1997)

Task-Related Characteristics	Personal Characteristics	Organizational Characteristics
Force	Previous CTD	Equipment
Repetition	Habits and hobbies	Production Rate
Awkward joint posture	Diabetes	CTD statistics
Hand tools	Thyroid problems	Peer influence
Length of work shift	Age	Training
Low-frequency vibration tools	Arthritis and/or Degenerative Joint Disease (DJD)	Ergonomics program and Awareness

Occupational and personal risks can be visualized mathematically and calculated as individual formulae (as seen in equations 1 and 2).

$$\textit{Occupational risk equation}: R_1 = F(O) = a_1 w_1 + a_2 w_2 + \ldots a_n w_n \quad (1)$$

$$\textit{Personal risk equation}: R_2 = F(P) = b_1 x_1 + b_2 x_2 + \ldots b_n x_n \quad (2)$$

Where:

R = Risk Resultant Score
F(O) = Occupational Risk Function
F(P) = Personal Risk Function
a = Occupational Risk Variable Weights
w = Occupational Risk Multiplier Decimal Values
b = Personal Risk Variable Weights
x = Personal Risk Multiplier Decimal Values

The personal judgment and assessment by a practitioner of each category's individual risk variable levels (risk multipliers) is multiplied against a proposed set of relative weights for each risk group. For each equation, the practitioner's personal judgment of risk levels is represented by the variables *w* and *x* for equations 1 and 2, respectively.

These are given decimal values ranging from 0 to 1.0 (0 being no exposure, and 1 being high risk). Each of these multiplier ranges are also given a qualifier description such as 55 pounds or 10-15 stair flights so that decision assessment of a rank will require less time consumption. The risk factor weights are represented by the variables *a* and *b* for equations 1 and 2, respectively. These weights are for the actual occupational or personal risk variables that were previously mentioned in this chapter. Development of these variable weights and multipliers will be discussed further in the Model Development section of Chapter Four. The calculation of these risks were calculated at the end of each observation in order to 1) avoid mental overload during the task observation period and 2) allow sufficient time to calculate the risk levels appropriately. The resulting scores for each task or cumulatively for each individual, is known as *occupational resultant scores* (totals) or *personal resultant scores* (totals). *Risk levels* are also provided by the occupational assessment portion of the model (known as safe or hazardous).

Research Design

The Strain Index model was developed to assess likelihood of developing carpal tunnel syndrome in the wrists from occupational hazards (Moore & Garg, 1995). Formed around the idea of developing a tool that is not only qualitatively developed by subject matter experts but also quantitatively (by biomechanics, physiology, and epidemiology), the majority of the experimental design will be based on these studies by Moore and Garg (1994, 1995). It is hypothesized by this dissertation research that it is possible to yield a system capable of assessing occupational risk to the knee. With that, it is also understood that personal risk factors are also linked to knee disorders. Therefore, the individual risk assessment is included as well to add a truer sense of risk to the individual. So, in actuality two types of risk assessments took place during these task observations; 1) the risk quantity for the task as an initial risk baseline and 2) the individual's personal risk (with the exception of psychosocial variables), so that a more accurate holistic analysis can be revealed (Figure 3.2).

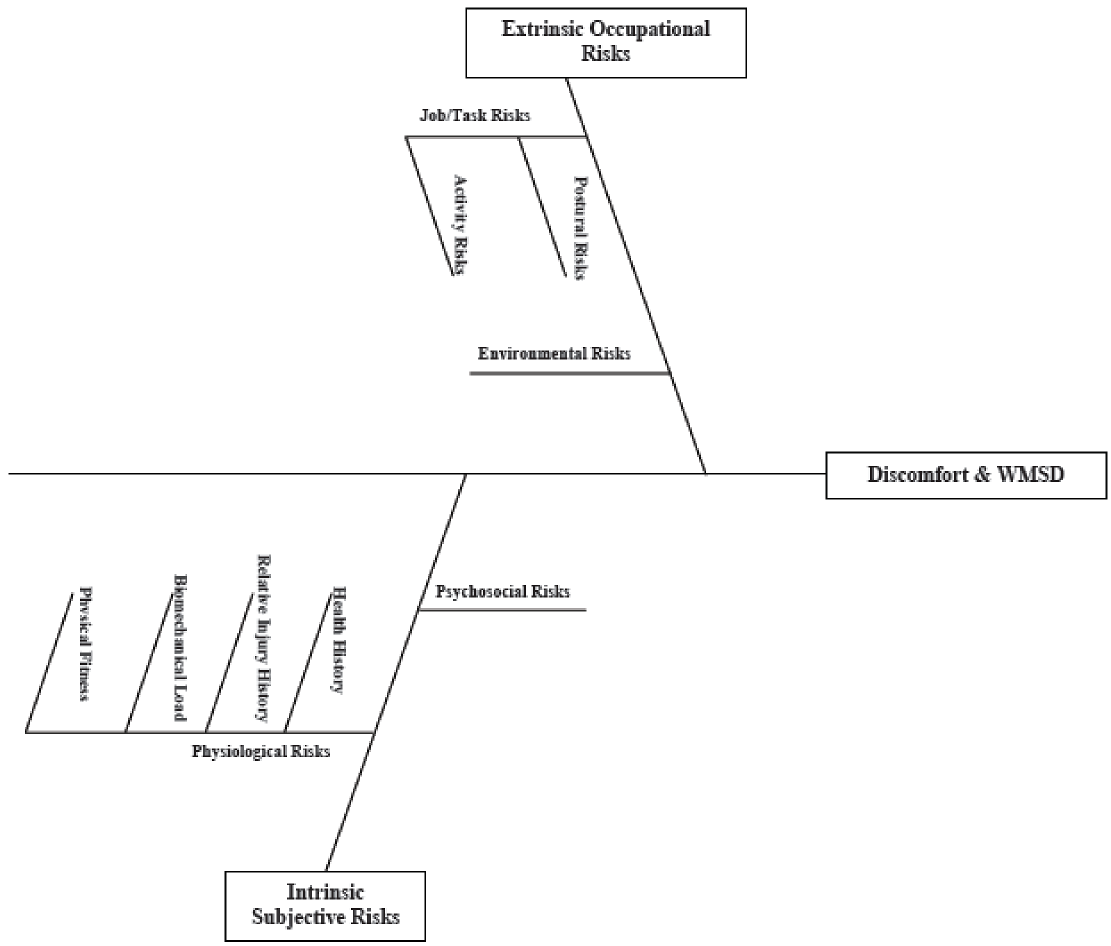

Figure 3.2 Cause and effect relationship for LE discomforts and disorders

The experimental design of this model was in three parts (model development, task hazard analysis, and model validation). First, was the final development of the risk model algorithms through the group assessment by subject matter experts. Once completed, the second stage was the actual observation and data collection stage (task hazard analysis) whose variables were previously described. In this stage there were actually two major data collection categories. The first was a hazard classification (Moore & Garg, 1994). This classification process was a qualitative stage performed by experienced practitioners. The results of their analyses helped reveal whether they felt that the task was either “safe” (no knee related risk) or “hazardous” (possible related knee risk) with regards to developing a knee disorder. In addition, if the task was rated as “hazardous”, then the possible body location of where the disorder may develop and the body side(s) it may develop on were also given.

The second category of the second stage data collection included the exposure assessment noted by Moore and Garg (1994) to be the ergonomic analysis of the particular task. This portion is actually the results of the model itself. Information collected was based on the literature review and consisted of task durations, postures and activities used, number of knee risk exertions (such as squatting, kneeling, etc.), duration of each exertion, upper body physical loading (lifting or carrying weights and how heavy they are), and if the knee is being used as hammer (impact stress). The type of tasks resulting from the preliminary data analysis showed that electrical wiring installation, plumbing, computer network installation, interior installation, and section joining were generally the areas where knee risks had been noted. It is the nature of these jobs to likely restrict workers to working in low lying areas. Also due to work environment is the fact that technicians were working in an aircraft assembly industry. This means that just to get to task locations sometimes required numerous iterations of ascending and descending staircases (a knee risk for two of three disorders) for multiple deck locations.

The final stage (model validation) involved two parts as well. The initial testing of the knee risk algorithms was validated against not just the hazard analysis and epidemiology, but also against the sample site's incident rates for the observed tasks. The incident rate was calculated by finding the number of confirmed cases that affected individuals with WMSDs from the task work areas and then dividing them by the number of full-time worker hours for that same task area. This is then multiplied by the number of labor hours for 100 full-time workers annually (equivalent to 200,000 labor hours) (Moore & Garg, 1994). Including epidemiological data, along with subject matter expert perception, and observational data (forming a quantitative assessment), allowed the initial validation of the model to be refined practically and realistically.

An additional test was added to the validation of the model. This addition was dubbed as "worst case scenarios" due to the extremely high or extremely low levels of risk that were tested against the models thresholds. This was especially necessary, as the data from the sample site did not test how the model would respond to more than two risk factors per task.

Data Analysis

Statistical analysis was conducted using Statistical Package for the Social Sciences (SPSS) version 13.0. Significance tests were conducted for the resulting scores of

LERA's hazardous and safe categorized tasks. These categories were established based on the hazard analysis performed by the subject matter experts. This initial test allowed us to see if there was a significant difference between the low scores that should result from safe tasks and the higher scores that stemmed from hazardous ones. The method chosen for this analysis was the Mann-Whitney U test. This was chosen due to the two data sets (hazardous and safe) having unequal non-parametric distributions (Elliot & Woodward, 2007; Moore & Garg, 1995). An alpha of 0.05 was selected. The hypotheses of the two Mann-Whitney U tests were as follows:

H_0: The two groups (safe and hazardous) have the same distribution

H_a: The two groups (safe and hazardous) do not have the same distribution

Outcomes of this significance test are seen in Chapter Four's Results section for the Final Iteration Test Results.

A one sample Student's To t Test (independent samples test) comparison was then made between the knee risk assessment model's calculated risk levels and the judgments made by the hazard analysis' subject matter experts. This test compared the hazard and safe judgments resulting from both sources using $\alpha = 0.05$. This particular test was chosen due to it being commonly used for gold standard mean comparisons (Elliot & Woodward, 2007). Additionally, the test was calculated for unequal variances. The two-tailed version for the hypotheses of this t Test is as follows:

$$H_0 : \mu = \mu_0 \qquad (3)$$

$$H_a : \mu \neq \mu_0 \qquad (4)$$

Where:

H_0 = Null hypothesis (the mean judgments of both the model and the hazard analysis are the same)

H_a = Second hypothesis (the mean judgments of both the model and the hazard analysis are not the same)

μ_0 = Hypothesized mean of the hazard analysis (gold standard)

μ = Population mean of the model results

CHAPTER FOUR : RESULTS

Data collection, as mentioned in the methodology of Chapter Three, was divided into three groups. These groups include the 1) model development subject matter experts group, 2) incident rate data, hazard classification analysis subject matter experts, and 3) observational data from watching tasks and collecting surveys. The validation information gathered from feeding data through the model and the cross comparisons of the results against the hazard analysis and incident rates are also included in the contents of this chapter.

Model Development

As mentioned in Chapter Three's methodology of the Model Development section, a subject matter expert model development committee was formed consisting of seven members from research groups in industry, government, academia, and consulting fields across the US. This group's lower extremity experience ranged from industrial ergonomics, to occupational biomechanics and sports physiology. Their purpose was to aid in refining the exposure details of the 16 initial risk variables taken from the literature and compiling them into an initial knee risk assessment model (seen in Tables 3-2 through 3-5). Subject matter experts were given a model development packet (Appendix C) that consisted of two response sections; 1) risk factor weights and 2) risk factor multipliers. This modeling packet also included additional information for topic background on the three knee disorders, their associated risk factors, and a hypothetical example of a knee risk detecting spreadsheet.

Initial Model Results

Risk Factor Weights

The weights section gave subject matter experts the ability to choose a given weight of association for the relationship between exposure to a risk factor and the development of a knee disorder. All three knee disorders (knee OA, knee meniscus tears, and knee bursitis) were consolidated into a general knee disorder result. Participants reviewed each risk factor's individual contribution towards the development of a knee disorder and chose the weighting from a scale of 1-7 (1-weak association; 4-moderate association; 7-strong association) using integers only. The results of each of the seven subject matter experts are given in Table 4-1. Statistics of each risk variable is shown in Table 4-2 and disclose the arithmetic mean, the standard deviation, the median, minimum and maximum given weights, and the overall, occupational, and personal ranks. The arithmetic mean for each variable was used as a measure of the model development committee's overall opinion of risk association strength. Ranking the mean risks from strongest to weakest association started with using the knee as hammer (6.571), followed by knee injury/surgery history (6.143), prolonged contact stress against the knee other than when kneeling (5.857), kneeling (5.714), crawling (5.571), BMI (5.429), squatting/crouching (5.143), physically intensive habits and hobbies outside of work (4.857), stair/ladder climbing (4.0), lifting/carrying objects (manual material handling) (3.857), standing up from a kneeling or squatting position (3.857), age (3.857), use of vibrating tools (3.0), chair sitting while driving (2.429), standing (2.143), and walking (2.0). These means were used in refining the model.

Table 4-1 Weights given by the seven subject matter experts for each of the 16 risk variables

		Subject Matter Expert Participant#						
Risk Variable#	**Risk Variable**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	Kneeling	6	5	5	7	4	7	6
2	Squatting/Crouching	4	6	5	5	4	7	5
3	Crawling	7	5	6	7	4	7	3
4	Stair/Ladder Climbing	3	4	4	5	5	5	2
5	Lifting/carrying ≥ 10 items per day	2	4	6	4	4	5	2
6	Walking	1	2	3	2	1	4	1
7	Standing	1	1	3	3	1	4	2
8	Standing up from a kneel/squat/crawl	1	2	7	4	5	5	3
9	Chair sitting (while driving)	1	2	1	3	3	6	1
10	Body Mass Index	6	5	7	5	6	7	2
11	Past knee injury/surgery	5	7	7	7	7	7	3
12	Age	3	2	4	6	4	4	4
13	Vibrating Tools	2	1	5	2	2	7	2
14	Using the knee as a hammer	7	7	7	6	5	7	7
15	Prolonged contact stress against the patella bone other than when kneeling	5	6	6	5	5	7	7
16	Physically intensive habits/hobbies that could affect the knee	3	5	4	4	5	6	7

Gray highlighted text signifies occupational risk factors whereas the tan color represents personal risk factors.

Table 4-2 Statistical measures of the seven subject matter experts for each risk factor

		Subject Matter Expert Statistical Measures							
Risk Variable#	Risk Variable	Mean	Std. Dev.	Median	Min	Max	Overall Rank	Occupational Rank	Personal Rank
1	Kneeling	5.714	1.113	6	4	7	4	3	
2	Squatting/Crouching	5.143	1.069	5	4	7	7	5	
3	Crawling	5.571	1.618	6	3	7	5	4	
4	Stair/Ladder Climbing	4.000	1.155	4	2	5	9	6	
5	Lifting/carrying ≥ 10 items per day	3.857	1.464	4	2	6	10	7	
6	Walking	2.000	1.155	2	1	4	16	12	
7	Standing	2.143	1.215	2	1	4	15	11	
8	Standing up from a kneel/squat/crawl	3.857	2.035	4	1	7	10	7	
9	Chair sitting (while driving)	2.429	1.813	2	1	6	14	10	
10	Body Mass Index	5.429	1.718	6	2	7	6		2
11	Past knee injury/surgery	6.143	1.574	7	3	7	2		1
12	Age	3.857	1.215	4	2	6	10		4
13	Vibrating Tools	3.000	2.160	2	1	7	13	9	
14	Using the knee as a hammer	6.571	0.787	7	5	7	1	1	
15	Prolonged contact stress against the patella bone other than when kneeling	5.857	0.900	6	5	7	3	2	
16	Physically intensive habits/hobbies that could affect the knee	4.857	1.345	5	3	7	8		3

Gray highlighted text signifies occupational risk factors whereas the tan color represents personal risk factors.

Risk Factor Multipliers

The multiplier section of the model development packet consisted of a multiplier threshold description (qualifier) and quantity for each of the 16 variables. This section is where subject matter expert opinion varied the most and multiple meetings were required to create a consensus. Tables 4-3 – 4-19 display the results of the originally suggested threshold descriptions and quantities as well as each of the seven subject matter expert judgments.

Table 4-3 Results of subject matter expert judgment for kneeling

Participant#	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
1	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
2	> 1 hrs per work day	0.5-1 hrs per work day	NA	< 0.5 hrs per work day	NA	1.00	0.70	NA	0.00	NA
3	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
4	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.75	0.50	0.25	NA
5	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
6	> 1 hrs per work day	0.5-1 hrs per work day	< 0.5 hr per work day	NA	NA	1.00	0.50	0.25	NA	NA
7	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.75	0.50	0.00	NA

NA = Not Applicable

Table 4-4 Results of subject matter expert judgment for squatting/crouching

Participant#	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
1	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.00	0.00	NA
2	> 1 hr per work day	0.5-1 hrs per work day	NA	< 0.5 hrs per work day	NA	1.00	0.70	NA	0.00	NA
3	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
4	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.75	0.50	0.00	NA
5	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
6	> 1 hrs per work day	0.5-1 hrs per work day	< 0.5 hr per work day	NA	NA	1.00	0.50	0.25	NA	NA
7	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.60	0.30	0.10	NA

NA = Not Applicable

Table 4-5 Results of subject matter expert judgment for crawling

	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
Participant#	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
1	> 4 hrs per work day	>2 & <4 hrs per work day	1-2 hrs per work day	< 1 hr per work day	NA	1.00	0.75	0.50	0.00	NA
2	> 2 hrs per work day	1-2 hrs per work day	0.25-1 hr per work day	< 0.25 hrs per work day	NA	1.00	0.80	0.50	0.00	NA
3	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
4	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
5	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
6	> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hr per work day	NA	NA	1.00	0.50	0.25	NA	NA
7	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA

NA = Not Applicable

Table 4-6 Results of subject matter expert judgment for stair/ladder climbing

	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
Participant#	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	> 30 flights per day	15-30 flights per day	10-14 flights per day	< 10 flights per day	NA	1.00	0.50	0.25	0.00	NA
1	> 30 flights per day	NA	NA	< 30 flights per day	NA	0.50	NA	NA	0.00	NA
2	> 30 flights per day	15-30 flights per day	10-14 flights per day	< 10 flights per day	NA	1.00	0.50	0.25	0.00	NA
3	> 30 flights per day	15-30 flights per day	10-14 flights per day	< 10 flights per day	NA	1.00	0.50	0.25	0.00	NA
4	> 15 flights per day	10-15 flights per day	5-10 flights per day	< 5 flights per day	NA	1.00	0.80	0.50	0.00	NA
5	> 30 flights per day	15-30 flights per day	10-14 flights per day	< 10 flights per day	NA	1.00	0.50	0.25	0.00	NA
6	> 30 flights per day	10-30 flights per day	5-10 flights per day	< 5 flights per day	NA	1.00	0.50	0.25	0.00	NA
7	> 30 flights per day	15-29 flights per day	6-14 flights per day	< 5 flights per day	NA	1.00	0.60	0.30	0.00	NA

NA = Not Applicable

Table 4-7 Results of subject matter expert judgment for lifting/carrying objects

	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
Participant#	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	Avg. ≥ 110 lbs per item	Avg. = 55-109 lbs per item	Avg. = 22-54 lbs per item	Avg. < 22 lbs per item	NA	1.00	0.50	0.25	0.00	NA
1	> 30,000 lbs per work day	10,000-30,000 lbs per work day	2,000-10,000 lbs per work day	< 2,000 lbs per work day	NA	1.00	0.75	0.50	0.00	NA
2	Avg. ≥ 70 lbs per item	Avg. = 50-70 lbs per item	Avg. = 15-50 lbs per item	Avg. < 15 lbs per item	NA	1.00	0.70	0.50	0.00	NA
3	Avg. ≥ 110 lbs per item	Avg. = 55-109 lbs per item	Avg. = 22-54 lbs per item	Avg. < 22 lbs per item	NA	1.00	0.50	0.25	0.00	NA
4a	> 10 times per work day	5-10 times per work day	1-5 times per work day	0 times per work day	NA	1.00	0.75	0.50	0.00	NA
4b	> 30 times per work day	20-30 times per work day	10-20 times per work day	0-10 times per work day	NA	1.00	0.75	0.50	0.00	NA
4c	> 50 times per work day	40-50 times per work day	20-40 times per work day	0-20 times per work day	NA	1.00	0.75	0.50	0.00	NA

NA = Not Applicable

Participant#	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	Avg. ≥ 110 lbs per item	Avg. = 55-109 lbs per item	Avg. = 22-54 lbs per item	Avg. < 22 lbs per item	NA	1.00	0.50	0.25	0.00	NA
5	Avg. ≥ 110 lbs per item	Avg. = 55-109 lbs per item	Avg. = 22-54 lbs per item	Avg. < 22 lbs per item	NA	1.00	0.50	0.25	0.00	NA
6	Avg. ≥ 22 lbs per item	Avg. = 10-20 lbs per item	Avg. = 0-10 lbs per item	NA	NA	1.00	0.50	0.25	NA	NA
7	Avg. ≥ 110 lbs per item	Avg. = 55-109 lbs per item	Avg. = 22-54 lbs per item	Avg. < 22 lbs per item	NA	1.00	0.60	0.30	0.10	NA

NA = Not Applicable

Table 4-8 Results of subject matter expert judgment for walking

Participant#	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	> 2 miles per work day	1-2 miles per work day	0.5-1 mile per work day	< 0.5 miles per work day	NA	1.00	0.50	0.25	0.00	NA
1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	> 5 miles per work day	3-5 miles per work day	1-2 miles per work day	< 1 mile per work day	NA	1.00	0.50	0.20	0.00	NA
3	> 2 miles per work day	1-2 miles per work day	0.5-1 mile per work day	< 0.5 miles per work day	NA	1.00	0.50	0.25	0.00	NA
4	> 2 miles per work day	1-2 miles per work day	0.5-1 mile per work day	< 0.5 miles per work day	NA	1.00	0.50	0.25	0.00	NA
5	> 2 miles per work day	1-2 miles per work day	0.5-1 mile per work day	< 0.5 miles per work day	NA	1.00	0.50	0.25	0.00	NA
6	> 2 miles per work day	1-2 miles per work day	0.5-1 mile per work day	< 0.5 miles per work day	NA	1.00	0.50	0.25	0.00	NA
7	> 2 miles per work day	1-2 miles per work day	0.5-1 mile per work day	< 0.5 miles per work day	NA	1.00	0.50	0.25	0.00	NA

NA = Not Applicable

Table 4-9 Results of subject matter expert judgment for standing

Participant#	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hrs per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hrs per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
3	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hrs per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
4	> 1 hr per work day	0.75-1 hrs per work day	0.5-0.75 hrs per work day	< 0.5 hrs per work day	NA	1.00	0.75	0.25	0.00	NA
5	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hrs per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
6	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hrs per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
7a	> 4 hrs per work day	2-4 hrs per work day	1-2 hrs per work day	< 1 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
7	> 4 hrs per work day	2-4 hrs per work day	1-2 hrs per work day	< 1 hrs per work day	NA	1.00	0.75	0.50	0.00	NA

NA = Not Applicable

Table 4-10 Results of subject matter expert judgment for standing up from a kneel/crawl/squat

	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
Participant#	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	> 30 times per work day	10-15 times per work day	10 times per work day	< 10 times per work day	NA	1.00	0.50	0.25	0.00	NA
1	> 30 times per work day	NA	NA	< 30 times per work day	NA	0.25	NA	NA	0.00	NA
2	> 30 times per work day	20-29 times per work day	10-19 times per work day	< 10 times per work day	NA	1.00	0.50	0.25	0.00	NA
3	> 30 times per work day	10-15 times per work day	10 times per work day	< 10 times per work day	NA	1.00	0.50	0.25	0.00	NA
4	> 30 times per work day	10-15 times per work day	10 times per work day	< 10 times per work day	NA	1.00	0.50	0.25	0.00	NA
5	> 30 times per work day	10-15 times per work day	10 times per work day	< 10 times per work day	NA	1.00	0.50	0.25	0.00	NA
6	> 30 times per work day	20-30 times per work day	10-20 times per work day	< 10 times per work day	NA	1.00	0.50	0.25	0.00	NA
7	> 30 times per work day	10-15 times per work day	10 times per work day	< 10 times per work day	NA	1.00	0.50	0.25	0.00	NA

NA = Not Applicable

Table 4-11 Results of subject matter expert judgment for standing up from chair sitting while driving > 4 hrs per day

Participant#	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
3	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
4	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
5	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
6	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
7	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00

NA = Not Applicable

Table 4-12 Results of subject matter expert judgment for body mass index (BMI)

Participant#	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	> 35	30-35	25-29.9	< 25	NA	1.00	0.50	0.25	0.00	NA
1	> 35	30-35	25-29.9	< 25	NA	1.50	0.75	0.25	0.00	NA
2	> 35	30-35	25-29.9	< 25	NA	1.00	0.70	0.10	0.00	NA
3	> 30	25.0-29.9	18.5-24.9	< 18.5	NA	1.00	0.50	0.25	0.00	NA
4	> 35	30-35	25-29.9	< 25	NA	1.00	0.75	0.50	0.00	NA
5	> 35	30-35	25-29.9	< 25	NA	1.00	0.75	0.50	0.00	NA
6	> 35	30-35	25-29.9	< 25	NA	1.00	0.50	0.25	0.00	NA
7	> 35	30-35	25-29.9	< 25	NA	1.00	0.50	0.25	0.00	NA

NA = Not Applicable

Table 4-13 Results of subject matter expert judgment for past knee injury/surgery

Participant#	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
1	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
2	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
3	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
4	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
5	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
6	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
7	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00

NA = Not Applicable

Table 4-14 Results of subject matter expert judgment for age

Participant#	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	> 64	55-64	45-54 (women)	< 45 women; < 55 men	NA	1.00	0.50	0.25	0.00	NA
1	≥ 55-64	NA	NA	< 55	NA	0.75	NA	NA	0.00	NA
2	> 64	55-64	45-54 (women)	< 45 women; < 55 men	NA	1.00	0.50	0.25	0.00	NA
3	> 64	55-64	45-54 (women)	< 45 women; < 55 men	NA	1.00	0.50	0.25	0.00	NA
4	> 64	55-64	45-54 (women)	< 45 women; < 55 men	NA	1.00	0.50	0.25	0.00	NA
5	> 64	55-64	45-54 (women)	< 45 women; < 55 men	NA	1.00	0.50	0.25	0.00	NA
6	> 64	55-64	45-54 (women)	< 45 women; < 55 men	NA	1.00	0.50	0.25	0.00	NA
7	> 64	55-64	45-54 (women)	< 45 women; < 55 men	NA	1.00	0.50	0.25	0.00	NA

NA = Not Applicable

Table 4-15 Results of subject matter expert judgment for using vibrating tools

Participant#	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
3	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
4	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
5	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
6	> 1 hrs per work day	0.5-1 hrs per work day	< 0.5 hr per work day	NA	NA	1.00	0.50	0.25	NA	NA
7	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA

NA = Not Applicable

Table 4-16 Results of subject matter expert judgment for using the knee as a hammer

	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
Participant#	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
1	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.50
2	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
3	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
4	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
5	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
6	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00
7	NA	NA	NA	No	Yes	NA	NA	NA	0.00	1.00

NA = Not Applicable

Table 4-17 Results of subject matter expert judgment for prolonged contact stress against the knee (except when kneeling)

	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
Participant#	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
1	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.75	0.50	0.00	NA
2	> 1 hr per work day	0.5-1 hrs per work day	NA	< 0.5 hrs per work day	NA	1.00	0.70	NA	0.00	NA
3	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
4	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.75	0.50	0.00	NA
5	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.50	0.25	0.00	NA
6	> 1 hrs per work day	0.5-1 hrs per work day	< 0.5 hr per work day	NA	NA	1.00	0.50	0.25	NA	NA
7	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day	NA	1.00	0.75	0.50	0.00	NA

Table 4-18 Results of subject matter expert judgment for physically intensive habits/hobbies that could affect the knee

Participant#	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	Soccer; Rugby; Football; Running; Swimming; Martial Arts; Gymnastics	Hiking, Biking	Gardening	No physical habits/hobbies that affecting the knee	NA	1.00	0.50	0.25	0.00	NA
1	Soccer; Rugby; Football; Running; Swimming; Martial Arts; Gymnastics	Hiking, Biking	Gardening	No physical habits/hobbies that affecting the knee	NA	0.50	0.00	0.00	0.00	NA
2	Soccer; Rugby; Football; Running; Swimming; Martial Arts; Gymnastics	Hiking, Biking	Gardening	No physical habits/hobbies that affecting the knee	NA	1.00	0.50	0.25	0.00	NA
3	Soccer; Rugby; Football; Running; Swimming; Martial Arts; Gymnastics	Hiking; Biking; Gardening; Resistance Training	Walking	No physical habits/hobbies that affecting the knee	NA	1.00	0.50	0.25	0.00	NA

NA = Not Applicable

Participant#	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	Soccer; Rugby; Football; Running; Swimming; Martial Arts; Gymnastics	Hiking, Biking	Gardening	No physical habits/hobbies that affecting the knee	NA	1.00	0.50	0.25	0.00	NA
4	Gardening, running, soccer, gymnastics, rugby, martial arts	Hiking, Biking	Swimming	No physical habits/hobbies that affecting the knee	NA	1.00	0.50	0.25	0.00	NA
5	Soccer; Rugby; Football; Running; Swimming; Martial Arts; Gymnastics	Hiking, Biking	Gardening	No physical habits/hobbies that affecting the knee	NA	1.00	0.50	0.25	0.00	NA
6	Soccer; Rugby; Football; Running; Swimming; Martial Arts; Gymnastics	Hiking, Biking	Gardening	No physical habits/hobbies that affecting the knee	NA	1.00	0.50	0.25	0.00	NA

NA = Not Applicable

Participant#	Multiplier Threshold Descriptions					Multiplier Threshold Quantities				
	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk	High Risk	Moderate Risk	Low Risk	No Risk	Applicable Risk
Original	Soccer; Rugby; Football; Running; Swimming; Martial Arts; Gymnastics	Hiking, Biking	Gardening	No physical habits/hobbies that affecting the knee	NA	1.00	0.50	0.25	0.00	NA
7	Soccer; Rugby; Football; Running; Swimming; Martial Arts; Gymnastics	Hiking, Biking, Gardening	Dancing	No physical habits/hobbies that affecting the knee	NA	1.00	0.50	0.25	0.00	NA

NA = Not Applicable

Final Model Results

It is the intent of this research to develop a model that can be developed into a tool for practitioners to use. With this in mind, the model development committee refined the model results seen initially from 16 risk factors to 11 by either removing or combining variables (Tables 4-19 and 4-20). Risk factor weights were assigned whole numbers that ranged 2 - 7. Depending on the variable, risk multiplier exposure levels may be Boolean (exist or not exist), be high, moderate, or minimal risk, or be high, moderate, low, or no risk. Kneeling, squatting/crouching, and crawling were all treated similarly so that each received a weight of 6.0 and had a risk exposure levels ranging from greater than one hour (high risk) to less than 30 minutes (minimal risk).

As mentioned previously in the literature for knee OA and stair climbing, a flight of stairs was found to have a mean of 16.5 steps. This number would be necessary if work environments involve numerous counts of short flights. The resulting weight for this risk factor was 4.0 with a high exposure level being more than 15 flights per work day and minimal being less than 10.

The variable for lifting and moving was changed into a subset of 3 variables. These subsets are classified by mean object weight and were labeled as extremely heavy (≥ 110 pounds) with a risk weight of 5.0, heavy (≥ 55 pounds) had a risk weight of 4.0, and moderately heavy (≥ 22 pounds) 3.0. Depending on the mean object weight during the task, the number of lifts to achieve a risk category is reduced as the weight increases. If multiple weights are handled for one task, first average the total weight for the task (to find one's appropriate weight subset), then sum the count of all the risks and apply the results to the correct weight subset.

Table 4-19 Occupational risk factor weights and multiplier exposure levels

Risk Var.#	Risk Variable	Risk Weight	Risk Multipliers		
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day
			1.00	0.75	0.25
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day
			1.00	0.75	0.25
3	Crawling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day
			1.00	0.75	0.25
4	Stair or Ladder Climbing	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 15 flights per day	10-15 flights per day	< 10 flights per day
			1.00	0.50	0.25
5a	Lifting or carrying ≥ 110 lbs per item (**Extremely Heavy**)	5.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 10 times per work day	5-10 times per work day	1-5 times per work day
			1.00	0.75	0.50
5b	Lifting or carrying ≥ 55 lbs per item (**Heavy**)	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 30 times per work day	20-30 times per work day	10-20 times per work day
			1.00	0.75	0.50
5c	Lifting or carrying ≥ 22 lbs per item (**Moderately Heavy**)	3.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 50 times per work day	40-50 times per work day	20-40 times per work day
			1.00	0.75	0.50

Risk Var.#	Risk Variable	Risk Weight	Risk Multipliers		
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**	
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing	
			0.00	1.00	
7	Using the knee as a hammer	7.00	**No Risk**	**Applicable Risk**	
			< 20 impacts per day	≥ 20 impacts per day	
			0.00	1.00	
8	Prolonged contact stress against the patella bone other than when kneeling	5.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day
			1.00	0.75	0.25

Table 4-20 Personal risk factor weights and multiplier exposure levels

Risk Var.#	Risk Variable	Risk Weight	Risk Multipliers			
1	Body Mass Index	6.00	**High Risk**	**Moderate Risk**	**Low Risk**	**No Risk**
			> 35	30-35	25-29.9	< 25
			1.00	0.75	0.10	0.00
2	Past Knee Injury or Surgery	6.00	**No Risk**	**Applicable Risk**		
			No Injury History	Injury or Surgical History		
			0.00	1.00		
3	Age	4.00	**No Risk**	**Applicable Risk**		
			< 55 years old	≥ 55 years old		
			0.00	1.00		

For situations, where you are calculating the cumulative risk over a series of tasks, calculate the average weight for the objects handled overall, then sum together the total count of all exposures and apply the count towards the subset appropriate to the mean weight. In the event that multiple high risk multipliers from different subsets are triggered over a series of tasks, then assume that the high risk of the heaviest weight group will take precedence for the total risk calculation. This is especially for if exposure counts noticeably exceed well beyond the criteria of high risk (see the beverage delivery driver example later on in this chapter's Worst Case Scenarios).

Standing and walking were combined into one variable (risk weight of 2.0) where either risk accumulated into a quantity of time exposure ($\geq$ 2 hours). Walking can also be measured as a distance, which in that case can be converted into time by dividing by the mean walking speed of 3 miles per hour.

Using the knee as a hammer was seen by subject matter experts also as a Boolean variable where at least 20 impacts per day would be deemed as a knee risk (risk weight of 7.0). This quantity was based on the recommendations offered by the Washington Industrial Safety and Health Act (WISHA) for knee kicking (Washington State Legislature, 2000).

The last refined variable was prolonged contact stress against the knee (except for when kneeling). This variable's results were developed in similar fashion to the kneeling and crawling variables except that it was given a risk weight of 5.0 while maintaining the same risk exposure levels.

Personal risk factors were put through a similar vetting process by the committee (Table 4-20). BMI as a risk was given a risk weight of 6.0 and is the only variable to carry four risk multiplier exposure categories. Very obese (> 35) is given the highest risk whereas normal weight (< 25) was not considered a risk. History of knee injury also led the committee to place a high risk weight of 6.0 on this Boolean variable as the literature shows it to be of great concern. Anderson and Felson (1988) mentioned in their study, that an increase in age is known to be associated with an increase in prevalence of knee OA. Therefore, age was also given consideration in the model when workers were at least 55 years old. This variable had a risk weighting of 4.0.

Incident Rate Data

Incident rate data were obtained from the sample site's safety recording system for 2005 data (January – December). Unfortunately, the annual number of labor hours were not available for the specific tasks but were only available for the general task locations they were found in. Therefore, these incident rates should be taken into consideration with a grain of salt. With the number of cumulative disorders that occurred (for OSHA recorded lost work day cases) and the available labor hours captured, incident rates for each general task location were then calculated for every 100 full-time workers. These incident rates were calculated for five general task areas that associated with portions of the aircraft assembly process. These incident rates were 6.1, 3.8, 4.1, 5.5, and 3.8 (for areas

1, 2, 3, 4, and 5, respectively). From these five general task areas, 15 tasks were selected. Table 4-21 contains the 17 recorded observations, their associated task, and the incident rate applied to each task based on their general location.

Table 4-21 Task location incident rates based for every 100 full time workers

Observation #	Task #	Task Location Incident Rate	General Task Location#
1	1	6.1	1
2	2	6.1	1
3	3	6.1	1
4	4	6.1	1
5	5	5.5	4
6	6	5.5	4
7	6	5.5	4
8	7	5.5	4
9	6	5.5	4
10	8	3.8	5
11	9	3.8	5
12	10	3.8	5
13	11	4.1	3
14	12	4.1	3
15	13	3.8	2
16	14	3.8	2
17	15	3.8	2

Task Hazard Analysis

Hazard classification data consisted of three subject matter experts from the sample location's factories. These senior level ergonomists reviewed each of the 15 types of tasks that were captured by video and used their experiences and knowledge of WMSDs to provide judgments. To minimize the amount of time that subject matter experts would spend participating in the research, videos were sped up to between 8 and 16 times normal speed so that observation time was reduced to approximately 5 minutes or less. Subject matter experts were provided with detailed information for each task which included the observation's physical location, whether it was the right or left side of the aircraft, recorded task duration, shift, type of job (installation, fastening, or drilling) and task-work description. Each subject matter expert was then provided 15 identical questionnaires (one for each type of task) with the three types of questions. The primary goal of this hazard classification was to use professional judgment to assess the possibility of developing a knee disorder from the task (Question #1). Secondary to this would be the specifics of which (if not both) knee(s) would be affected (Question# 2 and 3). More details of these questions from this hazard analysis survey can be seen in Appendix C. Videos and questionnaires were completed by each subject matter expert individually of each other without communication between subject matter experts. Results for each question and the subject matter expert responses are provided in the Tables 4-22, 4-23, and 4-24.

Table 4-22 Subject matter expert opinion of task risk towards knee morbidity

Q1 - Task association to knee morbidity?			
Task#	SME1	SME2	SME3
1	No	No	No
2	Yes	Yes	No
3	No	Yes	Yes
4	Yes	Yes	No
5	No	No	No
6	No	No	No
7	No	No	No
8	Yes	No	No
9	No	Yes	Yes
10	Yes	Yes	No
11	Yes	Yes	Yes
12	Yes	Yes	Yes
13	No	Yes	No
14	No	No	No
15	No	No	No

Results of Table 4-22 reveal that for tasks 1, 5, 6, 7, 14, and 15, all three subject matter experts agreed that they felt no risk was posed to the knee of the individual. Only for tasks 11 and 12 had all the subject matter experts concurred with a knee risk confirmation. In between these risks, opinions differed. Tasks 2, 3, 4, 9, and 10 had 2 out of 3 subject matter experts stating that there were risks posed for the knee. Tasks 8 and 13 were the only two tasks where only one subject matter expert mentioned a risk exists for the knee.

Table 4-23 Subject matter expert opinion of which knee is likely to be affected from the task

Q2 – If association, is/are one or both knees affected?			
Task#	**SME1**	**SME2**	**SME3**
1	NA	NA	NA
2	Both	One	NA
3	NA	Both	Both
4	One	Both	NA
5	NA	NA	NA
6	NA	NA	NA
7	NA	NA	NA
8	Both	NA	NA
9	NA	Both	Both
10	Both	Both	NA
11	One	Both	Both
12	Both	Both	Both
13	NA	Both	NA
14	NA	NA	NA
15	NA	NA	NA

NA = Not Applicable

SMEs were asked in their second question to choose whether there was a risk for one knee or for both knees for the task that they observed. This question was only filled out if they stated on their first question that a risk existed for the knee. SME 1 felt that for tasks

2, 8, 10, and 12, risks were posed for both knees of the participant observed on the video. For tasks 4 and 11, they only chose one knee (left and right knee, respectively according to Table 4-23). SME 2 recorded that tasks 3, 4, 9, 10, 11, 12, and 13 all posed a risk for both knees of the mechanic they observed. Only in task 2 did they feel that the left knee was at risk (Tables 4-23 and 4-24). SME3 reported that they felt that tasks 3, 9, 11, and 12 posed risk for both knees.

Table 4-24 Task associated left or right knee morbidity

Q3 - If one knee, then is it left or right knee?			
Task#	**SME1**	**SME2**	**SME3**
1	NA	NA	NA
2	NA	Left	NA
3	NA	NA	NA
4	Left	NA	NA
5	NA	NA	NA
6	NA	NA	NA
7	NA	NA	NA
8	NA	NA	NA
9	NA	NA	NA
10	NA	NA	NA
11	Right	NA	NA
12	NA	NA	NA
13	NA	NA	NA
14	NA	NA	NA
15	NA	NA	NA

NA = Not Applicable

If we look at the three judgments given by the three subject matter experts in Table 4-22, a majority (2 of 3) vote can be decided. Table 4-25 shows what this result would look like. From this we can see which tasks are considered by subject matter experts to be safe or hazardous. So of the 17 observations, 7 of them (observations 2, 3, 4, 11, 12, 13, and 14) were considered as hazardous for the knee, whereas, the other 10 were judged to be safe.

Table 4-25 Task hazard analysis results

Hazard Analysis Summary			
Observation#	**Task#**	**Final Majority Ruling**	**Hazardous/ Safe for knees**
1	1	No	Safe
2	2	Yes	Hazardous
3	3	Yes	Hazardous
4	4	Yes	Hazardous
5	5	No	Safe
6	6	No	Safe
7	6	No	Safe
8	7	No	Safe
9	6	No	Safe
10	8	No	Safe
11	9	Yes	Hazardous
12	10	Yes	Hazardous
13	11	Yes	Hazardous
14	12	Yes	Hazardous
15	13	No	Safe
16	14	No	Safe
17	15	No	Safe

Task Related Data

Task based data was any data collected for anyone of the 15 different types of tasks observed. The type of data collected ranged from personal data (collected by questionnaire) to observational data (collected by video) and direct measure data (collected by weight scale).

Task Participant Data

For the 15 types of tasks, nine employees' information was captured for 17 individual observations. Table 4-26 displays the information of the nine participants and their personal data that was relative to knee risk factors. All participants were male ranging in age from 30 to 50 years old with a mean of 41. All participants were assembly workers whose installation type varied only by electrically or mechanically based systems. BMI also varied between 23 and 45 with a mean of 31. Two of the nine participants (1 and 5) had previous knee injuries and surgeries. Only two of the participants recalled any habits or hobbies outside of work that may pose a risk for the knee (5 and 9). When asked for the type of risk they felt may be relevant, participant 5 golfed on a monthly basis and 9 performed walking as an exercise every other day. Only participants 1 and 4 mentioned any current knee pain prior to the start of the task observation. Observations of the participants depended on the tasks found to be at risk. Some participants such as 1, 4, 5, 8, and 9 were observed across multiple tasks that may have been worked simultaneously, consecutively, or staggered throughout the work day.

Table 4-26 Task participant information

	Personal Information								
Participant#	Age	Gender	BMI	Past Knee Injuries/ Surgeries	If yes, list injuries/surgeries	Knee risk habits/hobbies	If yes, list	Any current knee pain	Tasks observed working in
1	40	Male	45	Yes	cruciate ligament repair (1986) right knee from sports inj.	No	NA	Yes-	1, 2, 3
2	45	Male	26	No	NA	No	NA	No	4
3	30	Male	27	No	NA	No	NA	No	8
4	43	Male	32	No	NA	No	NA	Yes	9, 10
5	48	Male	30	Yes	1980- arthroscopic surgery to remove rough edges in right knee	Yes	golf once per month	No	13, 14, 15
6	41	Male	23	No	NA	No	NA	No	6
7	32	Male	23	No	NA	No	NA	No	6
8	42	Male	36	No	NA	No	NA	No	5, 6, 7
9	50	Male	39	No	NA	Yes	walking ever other day	No	11, 12

NA = Not Applicable

Task Observational Data

As mentioned previously, there were 15 tasks and 17 individual task observations collected on video. Task risk exposure consists of both a task exposure count (number of individual risk exposures) and a task exposure duration (length of time per individual exposure summed into a total task duration). Table 4-27 gives further detail to each observation such as task predecessors, subject participation, and task durations. Task durations account only for the time that participants were filmed and do not account for time that may have been spent off camera performing task preparation, attending meetings or trainings, and gathering tools or parts. Therefore, there is an unaccounted for series of risks that may also be directly involved with completing the tasks that were video taped. Task durations varied from as little as 2 minutes and 41 seconds to as much as 3 and one half hours of work. Total recorded observational data used added up to 14 hours, 53 minutes and 9 seconds. Mean task duration for the 17 observations was 52 minutes and 32 seconds.

Table 4-27 Task and observation details

Observation#	Task#	Task Predecessor	Participant#	Task Duration
1	1	NA	1	0:11:45
2	2	1	1	1:40:45
3	3	1,2	1	0:17:10
4	4	NA	2	0:49:55
5	5	NA	8	0:24:07
6	6	5	8	0:52:42
7	6	NA	7	0:44:59
8	7	5,6	8	1:00:58
9	6	NA	6	0:02:41
10	8	NA	3	3:30:15
11	9	NA	4	0:06:29
12	10	9	4	2:01:48
13	11	NA	9	0:30:34
14	12	11	9	2:06:39
15	13	NA	5	0:09:38
16	14	13	5	0:13:41
17	15	13,14	5	0:09:03
		Total Observed Time		14:53:09
		Mean Task Time		0:52:32

NA = Not Applicable

Three types of occupational risk variables required the bilateral collection of left and right knee risk exposures. These were kneeling, using the knee as a hammer, and prolonged knee contact. The remaining data for the 12 occupational variables were collected from a unilateral perspective.

Looking at the details of the knee observations in Table 4-28 shows that from all the observations (for all applicable participants), total kneeling duration was 2 hours, 5 minutes, and 54 seconds. Mean exposure duration per task was 10 minutes and 30 seconds. Left knee total duration for all participants was 1 hour, 42 minutes, and 14 seconds. Right knee total duration for all participants was 1 hour, 28 minutes, and 24 seconds. The longest exposure duration for a task was for observation 14 at nearly 33 minutes. Minimum exposure duration per task was 1 minute and 4 seconds. Mean kneeling exposure per task was 10 minutes and 30 seconds. The left and right knee had means of 8 minutes and 31 seconds (left knee) and 7 minutes and 22 seconds (right knee). Total number of exposures varied based on the participant and the task. Total overall count was 106 exposures over the 12 tasks that involved kneeling. The greatest number of kneeling exposures during one task was for observation 10 at 45 counts (just over 24 minutes of exposure). The lowest count was 1 for task observations 1 and 4. Left and right knee exposure count totals were 63 and 83, respectively. Left and right knee count mean was 5.25 (left knee) and 6.92 (right knee) counts per task.

Table 4-28 Task observational data for kneeling

			Kneeling (All Knees)			Left Knee			Right Knee		
Observation#	Task#	Task Duration	Count	Total Duration	Avg. Duration	Count	Total Duration	Avg. Duration	Count	Total Duration	Avg. Duration
1	1	0:11:45	1	0:01:35	0:01:35	1	0:01:35	0:01:35	1	0:01:35	0:01:35
2	2	1:40:45	5	0:07:19	0:01:28	5	0:07:19	0:01:28	4	0:06:46	0:01:41
3	3	0:17:10	4	0:11:35	0:02:54	3	0:11:31	0:03:50	4	0:01:04	0:02:54
4	4	0:49:55	1	0:01:04	0:01:04	1	0:01:04	0:01:04	1	0:01:04	0:01:04
5	5	0:24:07									
6	6	0:52:42									
7	6	0:44:59									
8	7	1:00:58									
9	6	0:02:41									
10	8	3:30:15	45	0:24:21	0:00:32	6	0:01:06	0:00:11	44	0:24:20	0:00:33
11	9	0:06:29	2	0:04:24	0:02:12	2	0:04:24	0:02:12	2	0:04:24	0:02:12
12	10	2:01:48	19	0:27:14	0:01:26	19	0:27:14	0:01:26	8	0:16:28	0:02:03
13	11	0:30:34	4	0:05:14	0:01:18	4	0:05:14	0:01:18	3	0:04:46	0:01:35
14	12	2:06:39	10	0:32:57	0:03:18	10	0:32:57	0:03:18	7	0:21:47	0:03:07
15	13	0:09:38	9	0:07:21	0:00:49	7	0:07:12	0:01:02	6	0:05:30	0:00:55
16	14	0:13:41	3	0:00:33	0:00:11	2	0:00:21	0:00:10	2	0:00:22	0:00:11
17	15	0:09:03	3	0:02:17	0:00:46	3	0:02:17	0:00:46	1	0:00:18	0:00:18
	Total Duration	14:53:09	Total Time		2:05:54			1:42:14			1:28:24
	Avg. Duration	0:52:32	Mean Task Time		0:10:30			0:08:31			0:07:22
			Total Count		106			63			83
			Mean Task Count		8.83			5.25			6.92

Squatting or crouching was carried out by participants throughout 12 of the 17 observations (Table 4-29). Total exposure duration for all tasks accumulated to 8 minutes and 41 seconds whereas the mean time per task was just under 1 minute (at 43 seconds). The longest task exposure duration was for observation 10 at 4 minutes and 26 seconds and the shortest was for 2 seconds from observation 11. Total number of exposures for all applicable tasks was at 113 with a mean of 9.42 per task. The largest number of exposures for a task was at 40 for observation 10 (likely due to the task being the longest to complete).

Crawling was only noticed during two video observations which were observations 2 and 16 (Table 4-29). Task exposure durations were 22 seconds for observation 2 and 4 seconds for observation 16 totaling to 26 seconds overall. The total number of exposures for all tasks was a count of 3 (2 exposures for observation 2 and 1 for observation 16).

Table 4-29 Task observation details for squatting/crouching and crawling risks

			Squatting or Crouching			Crawling		
Observation#	Task#	Task Duration	Count	Total Duration	Avg. Duration	Count	Total Duration	Avg. Duration
1	1	0:11:45						
2	2	1:40:45	1	0:00:04	0:00:04	2	0:00:22	0:00:11
3	3	0:17:10	1	0:00:03	0:00:03			
4	4	0:49:55	5	0:00:31	0:00:06			
5	5	0:24:07	7	0:00:10	0:00:01			
6	6	0:52:42	8	0:00:31	0:00:04			
7	6	0:44:59	25	0:00:47	0:00:02			
8	7	1:00:58	3	0:00:04	0:00:01			
9	6	0:02:41	3	0:00:06	0:00:02			
10	8	3:30:15	40	0:04:26	0:00:08			
11	9	0:06:29	2	0:00:02	0:00:01			
12	10	2:01:48	17	0:01:53	0:00:07			
13	11	0:30:34						
14	12	2:06:39						
15	13	0:09:38						
16	14	0:13:41	1	0:00:04	0:00:04	1	0:00:04	0:00:04
17	15	0:09:03						
	Total Duration	14:53:09	Total Time		0:08:41	Total Time		0:00:26
	Avg. Duration	0:52:32	Mean Task Time		0:00:43	Mean Task Time		0:00:13
			Total Count		113	Total Count		3
			Mean Task Count		9.42	Mean Task Count		1.50

The total number of tasks with stair (step) climbing exposure was 7 (Table 4-30). The total number of steps climbed was 218 which was equivalent to 13.21 flights of stairs (for 16.5 steps per flight). Observation 6 had the highest number of steps climbed (63). This was equivalent to 3.82 flights. Observation 3 had the lowest number of steps climbed (1 step). The mean number of steps climbed per task was 31.14 (1.89 flights). Exposure counts for all tasks summed up to 83 with a mean task observation count of 11.86. The highest number of exposures was for observation 8 which was 24 and the lowest for observation 3 at 1 exposure.

Table 4-31 contains information for lifting/carrying and walking risks. Only one episode of carrying significant weight occurred (observation 10). In other observations, objects lifted or carried did not meet the minimum weight required for minimal risk (22 pounds). Observation 10 had 3 exposure counts with a total accumulated weight of 110 pounds and a mean task weight of 36.67 pounds.

There were 12 observations that had walking as a risk (Table 4-31). Total walking time for all tasks was at 23 minutes and 36 seconds (approximately 1.18 miles). Mean walking time per task was 1 minute and 58 seconds. The longest total observed walking duration for a task was for observation 10 (7 minutes and 5 seconds). The shortest walking duration was for 10 seconds for observations 11 and 12. The total number of times participants were observed to walk for all applicable observations was for 191 exposures where each task had a mean walking count of 15.92 times.

Table 4-30 Task observation details for stair/ladder climbing

			Stair/Ladder Climbing			
Observation#	Task#	Task Duration	Count	Total Steps	Avg. Steps	# of Flights
1	1	0:11:45				
2	2	1:40:45	9	9	1	0.55
3	3	0:17:10	1	1	1	0.06
4	4	0:49:55				
5	5	0:24:07	11	39	3.55	2.36
6	6	0:52:42	20	63	3.15	3.82
7	6	0:44:59	16	60	3.75	3.64
8	7	1:00:58	24	36	1.50	2.18
9	6	0:02:41	2	10	5.00	0.61
10	8	3:30:15				
11	9	0:06:29				
12	10	2:01:48				
13	11	0:30:34				
14	12	2:06:39				
15	13	0:09:38				
16	14	0:13:41				
17	15	0:09:03				
	Total Duration	14:53:09	Total Steps		218.00	
	Avg. Duration	0:52:32	Mean Steps per Task		31.14	
			Total Flights		13.21	
			Total Exposure Count		83	
			Mean Task Exp. Count		11.86	

Table 4-31 Task observation detail for lifting/carrying and walking risks

			Lifting/Carrying			Walking		
Observation#	Task#	Task Duration	Count	Total Weight	Avg. Weight	Count	Total Duration	Avg. Duration
1	1	0:11:45						
2	2	1:40:45				18	0:01:48	0:00:06
3	3	0:17:10				4	0:00:31	0:00:08
4	4	0:49:55				11	0:02:08	0:00:12
5	5	0:24:07				21	0:01:47	0:00:05
6	6	0:52:42				17	0:02:54	0:00:10
7	6	0:44:59				21	0:02:19	0:00:07
8	7	1:00:58				15	0:03:10	0:00:13
9	6	0:02:41				5	0:00:30	0:00:06
10	8	3:30:15	3	110	36.67	74	0:07:05	0:00:06
11	9	0:06:29				2	0:00:10	0:00:05
12	10	2:01:48				1	0:00:10	0:00:10
13	11	0:30:34						
14	12	2:06:39						
15	13	0:09:38						
16	14	0:13:41				2	0:01:04	0:00:32
17	15	0:09:03						
	Total Duration	14:53:09	Total Task Weight		110.00	Total Time		0:23:36
	Avg. Duration	0:52:32	Mean Task Weight		36.67	Mean Task Time		0:01:58
						Total miles		1.18
			Total Count		3	Total Count		191
			Mean Task Count		3.00	Mean Task Count		15.92

Table 4-32 illustrates that standing was common amongst all of the observations (13 out of the 17). Total standing duration across all observations revealed a time of 4 hours, 9 minutes, and 34 seconds. Mean standing time for each of the applicable observations was 19 minutes and 12 seconds. The longest standing task duration was 1 hour, 24 minutes, and 3 seconds for observation 14, whereas observation 15 had the smallest duration of 15 seconds. The number of exposures to standing was 175 for all observations. This had a task count mean of 13.46 exposures. Observation 12 had a task count of 50 exposures and observations 9, 15, and 16 had only 3 exposures.

Standing up from a kneel, squat, crawl, or low lying sit position was also considered by both the literature and this study. 13 of the 17 observations were found to have occurrences of this risk (Table 4-32). Total number of exposures for all applicable observations was 128 with a mean of 9.85 per task. Some observations such as 5, 8, 15, and 16 only had one occurrence whereas observations 10 and 12 had 44 and 40, respectively.

Of all the observations recorded, none where found to have driving exposure, much less sitting while driving (Table 4-33). In addition, none of the participants were observed to use their knee as a hammer or have an object hit their knee rapidly.

Vibration from air operated tools was recorded during task observations (Table 4-33). Of the 17 observations, 13 were found to include hand power tools that rotated or hammered. The list of tools included drills and rivet guns. Total vibration exposure from tool usage for all the observed tasks summed up to 2 hours, 41 minutes, and 31 seconds. Mean task exposure duration was 12 minutes and 25 seconds. There were a total of 311 exposure counts with 23.92 being the mean per applicable observation. The highest exposure count was for task observation 14 at 117. The lowest exposure count was for observation 9, which just had 2. The longest task exposure duration was from observation 14 which was 34 minutes and 19 seconds. Observation 16 had the lowest task exposure duration of 45 seconds.

Table 4-34 displays observational information for prolonged knee contact stress. This excludes times when participants may have been kneeling. Only observation 13 displayed exposure to this type of risk. In this case, the mechanic was leaning his right knee against a portion of the aircraft structure while standing with his left leg. This single exposure was for a duration of 29 seconds.

Table 4-32 Task observation details for standing and standing up risks

			Standing			Standing up from kneel/squat/crawl/sit
Observation#	Task#	Task Duration	Count	Total Duration	Avg. Duration	Count
1	1	0:11:45				
2	2	1:40:45	5	0:02:19	0:00:28	8
3	3	0:17:10				3
4	4	0:49:55				6
5	5	0:24:07	16	0:19:56	0:01:15	1
6	6	0:52:42	15	0:17:58	0:01:12	4
7	6	0:44:59	15	0:35:54	0:02:24	15
8	7	1:00:58	12	0:25:23	0:02:07	1
9	6	0:02:41	3	0:01:36	0:00:32	2
10	8	3:30:15	23	0:06:14	0:00:16	44
11	9	0:06:29	4	0:01:53	0:00:28	2
12	10	2:01:48	50	0:31:08	0:00:37	40
13	11	0:30:34	8	0:22:10	0:02:46	
14	12	2:06:39	18	1:24:03	0:04:40	
15	13	0:09:38	3	0:00:15	0:00:05	1
16	14	0:13:41	3	0:00:45	0:00:15	1
17	15	0:09:03				
	Total Duration	14:53:09	Total Time		4:09:34	Total Count
	Avg. Duration	0:52:32	Mean Task Time		0:19:12	128
						Mean Task Count
			Total Count		175	9.85
			Mean Task Count		13.46	

Table 4-33 Task observation detail for chair sitting while driving, using vibration tools, and using the knee as a hammer risks

			Chair sitting while driving			Using Vibrating Tools			Using the knee as a hammer
Observation#	Task#	Task Duration	Count	Total Duration	Avg. Duration	Count	Total Duration	Avg. Duration	Count
1	1	0:11:45							
2	2	1:40:45							
3	3	0:17:10							
4	4	0:49:55				11	0:03:18	0:00:18	
5	5	0:24:07				21	0:14:21	0:00:41	
6	6	0:52:42				19	0:16:27	0:00:52	
7	6	0:44:59				24	0:30:08	0:01:15	
8	7	1:00:58				13	0:20:51	0:01:36	
9	6	0:02:41				2	0:00:51	0:00:26	
10	8	3:30:15							
11	9	0:06:29				15	0:03:31	0:00:14	
12	10	2:01:48				64	0:29:21	0:00:28	
13	11	0:30:34				12	0:05:26	0:00:27	
14	12	2:06:39				117	0:34:19	0:00:18	
15	13	0:09:38				7	0:00:51	0:00:07	
16	14	0:13:41				3	0:00:44	0:00:15	
17	15	0:09:03				3	0:01:23	0:00:28	
	Total Duration	14:53:09	Total Time		0:00:00	Total Time		2:41:31	Total Count
	Avg. Duration	0:52:32	Mean Task Time		0:00:00	Mean Task Time		0:12:25	0
									Mean Task Count
			Total Count		0	Total Count		311	0
			Mean Task Count		0	Mean Task Count		23.92	

Table 4-34 Task observation detail for prolonged contact stress against the knee (except when kneeling)

			Prolonged knee contact stress			Left Knee			Right Knee		
Observation#	Task#	Task Duration	Count	Total Duration	Avg. Duration	Count	Total Duration	Avg. Duration	Count	Total Duration	Avg. Duration
1	1	0:11:45									
2	2	1:40:45									
3	3	0:17:10									
4	4	0:49:55									
5	5	0:24:07									
6	6	0:52:42									
7	6	0:44:59									
8	7	1:00:58									
9	6	0:02:41									
10	8	3:30:15									
11	9	0:06:29									
12	10	2:01:48									
13	11	0:30:34	1	0:00:29	0:00:29	0	0	0:00:00	1	0:00:29	0:00:29
14	12	2:06:39									
15	13	0:09:38									
16	14	0:13:41									
17	15	0:09:03									
	Total Duration	14:53:09	Total Time		0:00:29			0:00:00			0:00:29
	Avg. Duration	0:52:32	Mean Task Time		0:00:29			0:00:00			0:00:29
			Total Count		1			0			1
			Mean Task Count		1.00			0.00			1.00

Validation Testing

As mentioned in Chapter Three's methodology explanation, we have adapted the validation method that was used in the Strain Index (Moore & Garg, 1994; Moore & Garg, 1995) development process for the lower extremity. Based on adapting knowledge from epidemiology, both the Strain Index's and this study's methods also involved using task related incident rates from the work testing location, using subject matter experts for professional opinion of a work-related risk (hazard assessment) for a form of model validation. This section will be divided into the initial validation examination of the knee model's results followed by a second iteration of validation for a more evolved and finalized model

Initial Iteration Test Results

The first validation test fed the data found from the task and employees questioned and observed into the risk assessment model. These results can be seen as a series of tables (4-36 – 4-57) and are arranged for each of the 9 participants.

Participant number 1's occupational risks (Tables 4-36 – 4-37) were spread over three observations and accounted for five types of risk exposures (kneeling, squatting/crouching, crawling, stair/ladder climbing and walking/standing). Walking/standing was not regarded as a risk by the knee model and therefore was not included in the resultant risk total. This participant received a total occupational resultant score of 5.50. Personal risk factors (Table 4-38) noticed include BMI and past injuries/surgeries. Total personal resultant score was 12.00.

Participant number 2's occupational risks (Table 4-39) amounted to three types of risk exposures (kneeling, squatting/crouching, and walking/standing) within one task observation. The walking/standing risk exposure level was not considered to be high enough for the knee model to include it. Total occupational resultant score was 3.00. Personal risk factors included only BMI and had a total personal resultant score of 0.60 (Table 4-40).

For participant number 3, only one task was observed and this led to discovering four types of risk factors (Table 4-41). Those factors were kneeling, squatting/crouching, lifting/carrying, and walking/standing. Lifting/carrying although having the at least the 22 pound requirement, did not meet the minimum number of lifts/carries to be counted as a risk. Walking/standing also did not meet the minimum two hours required to be considered as a risk. Total occupational resultant score was 3.00. Personal risk factors (Table 4-42) only accounted for a BMI risk which produced a total personal resultant score of 0.60.

Occupational risks for participant 4 looked at kneeling, squatting/crouching, and walking/standing dispersed over two observations (Tables 4-43 – 4-44). The walking/standing risk factor was not taken into account due to the low duration of exposure. The total occupational resultant score was 6.00. There was only one personal risk factor noticed and that was for BMI (Table 4-45). Total personal resultant score was 4.50.

Participant 5 was observed to work in three tasks. These tasks exposed him to three types of risk factors (kneeling, squatting/crouching, and walking/standing). One risk factor not included was walking/standing, due to the low duration of exposure. The total resultant score for these occupational risks was 3.00 (Table 4-46 – 4-47). Two personal risk factors were noticed for this participant. They were BMI and past knee injuries/surgeries (Table 4-48). This amounted to a total personal resultant score of 10.50.

The one task observed for participant number 6 included three types of occupational risk (squatting/crouching, stair/ladder climbing and walking/standing). Walking/standing did not meet the minimum requirement to be considered as a risk. The total occupational resultant score was 2.50 (Table 4-49). There were no personal risk factors triggered for the risk tool. So this meant that the total personal resultant score remained 0.00 (Table 4-50).

Participant number 7 was similar to participant number 6 in that he was also recorded for only one task observation and had been exposed to three types of occupational risk factors. These risks included squatting/crouching, stair/ladder climbing, and walking/standing and had a total occupational resultant score of 2.50 (Table 4-51). Walking/standing, although having more than 30 minutes of exposure, still did not meet the two hour requirement for risk consideration and was not included in this risk total.

The total personal resultant score was also 0.00 due to no personal risk factors being noted (Table 4-52).

The risk factors observed for participant 8 consisted of squatting/crouching, stair/ladder climbing, and walking/standing. These risk factors occurred during three task observations and summed to a total occupational resultant score of 2.50 (Table 4-53 – 4-54). Walking/standing was not included in this occupational risk total as it did not meet the minimum two hours. Meanwhile his personal risk factors accounted only for BMI and produced a personal total resultant score of 6.00 (Table 4-55).

Participant number 9 was the last subject observed by this study. He was noted to be observed for two tasks which exposed him to three types of risk factors (kneeling, walking/standing and prolonged knee contact stress). Not included in the occupational risk total was the variable for walking/standing, which did not meet the two hour minimum requirement. The total occupational resultant score was 5.75 (Table 4-56). The personal risk noticed for participant 9 was BMI which created a total personal resultant score of 6.00 (Table 4-57). Table 4-35 is an overview for each of the participant's occupational and personal risk totals.

Table 4-35 Participant resultant occupational and personal scores for the first validation iteration

Observation #	Task #	Participant #	Model Calculated Total Occupational Resultant Score	Number of Occupational Risk Factors Considered	Model Calculated Personal Resultant Score	Number of Personal Risk Factors Considered
1	1	1	5.50	4	12.00	2
2	2					
3	3					
4	4	2	3.00	3	0.60	1
10	8	3	3.00	4	0.60	1
11	9	4	6.00	3	4.50	1
12	10					
15	13	5	3.00	3	10.50	2
16	14					
17	15					
9	6	6	2.50	3	0.00	0
7	6	7	2.50	3	0.00	0
5	5	8	2.50	3	6.00	1
6	6					
8	7					
13	11	9	5.75	3	6.00	1
14	12					

Table 4-36 Participant #1's occupational risk results per task observed

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Task #2		Task #3	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day						
			1.00	0.75	0.25	0:01:35	1.50	0:07:19	1.50	0:11:35	1.50
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day						
			1.00	0.75	0.25			0:00:04	1.50	0:00:03	1.50
3	Crawling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day						
			1.00	0.75	0.25			0:00:22	1.50		
4	Stair or Ladder Climbing	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**
			> 15 flight s per day	10-15 flights per day	< 10 flights per day						
			1.00	0.50	0.25			0.55	1.00	0.06	1.00

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers		Task #1		Task #2		Task #3	
			No Risk	Applicable Risk	Recorded Duration	Resultant Score	Recorded Duration	Resultant Score	Recorded Duration	Resultant Score
6	Walking and/or Standing	2.00	< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing						
			0.00	1.00			0:04:07	0.00	0:00:31	0.00
					Total	1.50		5.50		4.00
					Number of Risk Factors Used	1		4		3

Table 4-37 Participant #1's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Total Risk	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day		
			1.00	0.75	0.25	0:20:29	1.50
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day		
			1.00	0.75	0.25	0:00:07	1.50
3	Crawling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day		
			1.00	0.75	0.25	0:00:22	1.50
4	Stair or Ladder Climbing	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Count**	**Resultant Score**
			> 15 flights per day	10-15 flights per day	< 10 flights per day		
			1.00	0.50	0.25	0.61	1.00

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Total Risk	
6	Walking and/or Standing	2.00	No Risk	Applicable Risk		Recorded Duration	Resultant Score
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing			
			0.00	1.00		0:04:38	0.00
						Total	5.50
						Number of Risk Factors Used	4

Table 4-38 Participant #1's total personal risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers				Total Risk	
1	Body Mass Index	6.00	**High Risk**	**Moderate Risk**	**Low Risk**	**No Risk**	**Recorded BMI**	**Resultant Score**
			> 35	30-35	25-29.9	< 25		
			1.00	0.75	0.10	0.00	45	6.00
2	Past Knee Injury or Surgery	6.00	**No Risk**	**Applicable Risk**			**Recorded Past Injury**	**Resultant Score**
			No Injury History	Injury or Surgical History				
			0.00	1.00			Yes	6.00
3	Age	4.00	**No Risk**	**Applicable Risk**			**Recorded Age**	**Resultant Score**
			< 55 years old	≥ 55 years old				
			0.00	1.00			40	0.00
							Total Score	12.00
							Number of Risk Factors Used	2

Table 4-39 Participant #2's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Total Risk	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day				
			1.00	0.75	0.25	0:01:04	1.50	0:01:04	1.50
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day				
			1.00	0.75	0.25	0:00:31	1.50	0:00:31	1.50
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing					
			0.00	1.00		0:02:08	0.00	0:02:08	0.00
						Total	3.00		3.00
						Number of Risk Factors Used	2		2

Table 4-40 Participant #2's total personal risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers				Total Risk	
1	Body Mass Index	6.00	High Risk	Moderate Risk	Low Risk	No Risk	Recorded BMI	Resultant Score
			> 35	30-35	25-29.9	< 25		
			1.00	0.75	0.10	0.00	26	0.60
2	Past Knee Injury or Surgery	6.00	No Risk	Applicable Risk			Recorded Past Injury	Resultant Score
			No Injury History	Injury or Surgical History				
			0.00	1.00			No	0.00
3	Age	4.00	No Risk	Applicable Risk			Recorded Age	Resultant Score
			< 55 years old	≥ 55 years old				
			0.00	1.00			45	0.00
							Total Score	0.60
							Number of Risk Factors Used	1

Table 4-41 Participant #3's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Total Risk	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day				
			1.00	0.75	0.25	0:24:21	1.50	0:24:21	1.50
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day				
			1.00	0.75	0.25	0:04:26	1.50	0:04:26	1.50
5c	Lifting/carrying ≥ 22 lbs per item (**Moderately Heavy**)	3.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**
			> 50 times per work day	40-50 times per work day	20-40 times per work day				
			1.00	0.75	0.50	3	0.00	3	0.00
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing					
			0.00	1.00		0:13:19	0.00	0:13:19	0.00
						Total	3.00		3.00
						Number of Risk Factors Used	2		2

Table 4-42 Participant #3's total personal risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers				Total Risk	
1	Body Mass Index	6.00	**High Risk**	**Moderate Risk**	**Low Risk**	**No Risk**	**Recorded BMI**	**Resultant Score**
			> 35	30-35	25-29.9	< 25		
			1.00	0.75	0.10	0.00	27	0.60
2	Past Knee Injury or Surgery	6.00	**No Risk**	**Applicable Risk**			**Recorded Past Injury**	**Resultant Score**
			No Injury History	Injury or Surgical History				
			0.00	1.00			No	0.00
3	Age	4.00	**No Risk**	**Applicable Risk**			**Recorded Age**	**Resultant Score**
			< 55 years old	≥ 55 years old				
			0.00	1.00			30	0.00
							Total Score	0.60
							Number of Risk Factors Used	1

Table 4-43 Participant #4's occupational risk results per task observed

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Task #2	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day				
			1.00	0.75	0.25	0:04:24	1.50	0:27:14	1.50
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day				
			1.00	0.75	0.25	0:00:02	1.50	0:01:53	1.50
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing					
			0.00	1.00		0:02:03	0.00	0:31:18	0.00
						Total	3.00		3.00
						Number of Risk Factors Used	2		2

Table 4-44 Participant #4's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Total Risk	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day		
			1.00	0.75	0.25	0:31:38	4.50
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day		
			1.00	0.75	0.25	0:01:55	1.50
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing			
			0.00	1.00		0:33:21	0.00
						Total	6.00
						Number of Risk Factors Used	2

Table 4-45 Participant #4's total personal risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers				Total Risk	
1	Body Mass Index	6.00	**High Risk**	**Moderate Risk**	**Low Risk**	**No Risk**	**Recorded BMI**	**Resultant Score**
			> 35	30-35	25-29.9	< 25		
			1.00	0.75	0.10	0.00	32	4.50
2	Past Knee Injury or Surgery	6.00	**No Risk**	**Applicable Risk**			**Recorded Past Injury**	**Resultant Score**
			No Injury History	Injury or Surgical History				
			0.00	1.00			No	0.00
3	Age	4.00	**No Risk**	**Applicable Risk**			**Recorded Age**	**Resultant Score**
			< 55 years old	≥ 55 years old				
			0.00	1.00			43	0.00
							Total Score	4.50
							Number of Risk Factors Used	1

Table 4-46 Participant #5's occupational risk results per task observed

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Task #2		Task #3	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day						
			1.00	0.75	0.25	0:07:21	1.50	0:00:33	1.50	0:02:17	1.50
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day						
			1.00	0.75	0.25			0:00:04	1.50		
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing							
			0.00	1.00		0:00:15	0.00	0:01:49	0:00:00		
						Total	1.50		3.00		1.50
						Number of Risk Factors Used	1		2		1

Table 4-47 Participant #5's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Total Risk	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day		
			1.00	0.75	0.25	0:10:11	1.50
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day		
			1.00	0.75	0.25	0:00:04	1.50
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing			
			0.00	1.00		0:02:04	0.00
						Total	3.00
						Number of Risk Factors Used	2

Table 4-48 Participant #5's total personal risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers				Total Risk	
1	Body Mass Index	6.00	**High Risk**	**Moderate Risk**	**Low Risk**	**No Risk**	**Recorded BMI**	**Resultant Score**
			> 35	30-35	25-29.9	< 25		
			1.00	0.75	0.10	0.00	30	4.50
2	Past Knee Injury or Surgery	6.00	**No Risk**	**Applicable Risk**			**Recorded Past Injury**	**Resultant Score**
			No Injury History	Injury or Surgical History				
			0.00	1.00			Yes	6.00
3	Age	4.00	**No Risk**	**Applicable Risk**			**Recorded Age**	**Resultant Score**
			< 55 years old	≥ 55 years old				
			0.00	1.00			48	0.00
							Total Score	10.50
							Number of Risk Factors Used	2

Table 4-49 Participant #6's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Total Risk	
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day				
			1.00	0.75	0.25	0:00:06	1.50	0:00:06	1.50
4	Stair/Ladder Climbing	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**
			> 15 flights per day	10-15 flights per day	< 10 flights per day				
			1.00	0.50	0.25	0.61	1.00	0.61	1.00
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing					
			0.00	1.00		0:02:06	0.00	0:02:06	0.00
						Total	2.50		2.50
						Number of Risk Factors Used	2		2

Table 4-50 Participant #6's total personal risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers				Total Risk	
1	Body Mass Index	6.00	**High Risk**	**Moderate Risk**	**Low Risk**	**No Risk**	**Recorded BMI**	**Resultant Score**
			> 35	30-35	25-29.9	< 25		
			1.00	0.75	0.10	0.00	23	0.00
2	Past Knee Injury or Surgery	6.00	**No Risk**	**Applicable Risk**			**Recorded Past Injury**	**Resultant Score**
			No Injury History	Injury or Surgical History				
			0.00	1.00			No	0.00
3	Age	4.00	**No Risk**	**Applicable Risk**			**Recorded Age**	**Resultant Score**
			< 55 years old	≥ 55 years old				
			0.00	1.00			41	0.00
							Total Score	0.00
							Number of Risk Factors Used	0

Table 4-51 Participant #7's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Total Risk	
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day				
			1.00	0.75	0.25	0:00:47	1.50	0:00:47	1.50
4	Stair/Ladder Climbing	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**
			> 15 flights per day	10-15 flights per day	< 10 flights per day				
			1.00	0.50	0.25	3.64	1.00	3.64	1.00
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing					
			0.00	1.00		0:38:13	0.00	0:38:13	0.00
						Total	2.50		2.50
						Number of Risk Factors Used	2		2

Table 4-52 Participant #7's total personal risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers				Total Risk	
1	Body Mass Index	6.00	**High Risk**	**Moderate Risk**	**Low Risk**	**No Risk**	**Recorded BMI**	**Resultant Score**
			> 35	30-35	25-29.9	< 25		
			1.00	0.75	0.10	0.00	23	0.00
2	Past Knee Injury or Surgery	6.00	**No Risk**	**Applicable Risk**			**Recorded Past Injury**	**Resultant Score**
			No Injury History	Injury or Surgical History				
			0.00	1.00			No	0.00
3	Age	4.00	**No Risk**	**Applicable Risk**			**Recorded Age**	**Resultant Score**
			< 55 years old	≥ 55 years old				
			0.00	1.00			32	0.00
							Total Score	0.00
							Number of Risk Factors Used	0

Table 4-53 Participant #8's occupational risk results per task observed

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Task #2		Task #3	
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day						
			1.00	0.75	0.25	0:00:10	1.50	0:00:31	1.5	0:00:04	1.50
4	Stair/Ladder Climbing	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 15 flights per day	10-15 flights per day	< 10 flights per day						
			1.00	0.50	0.25	2.36	1.00	3.82	1.00	2.18	1.00
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing							
			0.00	1.00		0:21:43	0.00	0:20:52	0:00:00	0:28:33	0.00
						Total	2.50		2.50		2.50
						Number of Risk Factors Used	2		2		2

Table 4-54 Participant #8's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Total Risk	
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day		
			1.00	0.75	0.25	0:00:45	1.50
4	Stair/Ladder Climbing	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
			> 15 flights per day	10-15 flights per day	< 10 flights per day		
			1.00	0.50	0.25	8.36	1.00
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing			
			0.00	1.00		1:11:08	0.00
						Total	2.50
						Number of Risk Factors Used	2

Table 4-55 Participant #8's total personal risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers				Total Risk	
1	Body Mass Index	6.00	**High Risk**	**Moderate Risk**	**Low Risk**	**No Risk**	**Recorded BMI**	**Resultant Score**
			> 35	30-35	25-29.9	< 25		
			1.00	0.75	0.10	0.00	36	6.00
2	Past Knee Injury or Surgery	6.00	**No Risk**	**Applicable Risk**			**Recorded Past Injury**	**Resultant Score**
			No Injury History	Injury or Surgical History				
			0.00	1.00			No	0.00
3	Age	4.00	**No Risk**	**Applicable Risk**			**Recorded Age**	**Resultant Score**
			< 55 years old	≥ 55 years old				
			0.00	1.00			42	0.00
							Total Score	6.00
							Number of Risk Factors Used	1

Table 4-56 Participant #9's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Task #2		Total Risk	
1	Kneeling	6.00	High Risk	Moderate Risk	Minimal Risk	Recorded Duration	Resultant Score	Recorded Duration	Resultant Score	Recorded Duration	Resultant Score
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day						
			1.00	0.75	0.25	0:05:14	1.50	0:32:57	4.50	0:38:11	4.50
6	Walking and/or Standing	2.00	No Risk	Applicable Risk		Recorded Duration	Resultant Score	Recorded Duration	Resultant Score	Recorded Duration	Resultant Score
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing							
			0.00	1.00		0:22:10	0.00	1:24:03	0:00:00	1:46:13	0.00
8	Prolonged contact stress against the patella bone other than when kneeling	5.00	High Risk	Moderate Risk	Minimal Risk	Recorded Duration	Resultant Score	Recorded Duration	Resultant Score	Recorded Duration	Resultant Score
			> 1 hr per work day	0.5-1 hrs per work day	< 0.5 hrs per work day						
			1.00	0.75	0.25	0:00:29	1.25			0:00:29	1.25
						Total	2.75		4.50		5.75
						Number of Risk Factors Used	2		1		2

Table 4-57 Participant #9's total personal risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers				Total Risk	
1	Body Mass Index	6.00	**High Risk**	**Moderate Risk**	**Low Risk**	**No Risk**	**Recorded BMI**	**Resultant Score**
			> 35	30-35	25-29.9	< 25		
			1.00	0.75	0.10	0.00	39	6.00
2	Past Knee Injury or Surgery	6.00	**No Risk**	**Applicable Risk**			**Recorded Past Injury**	**Resultant Score**
			No Injury History	Injury or Surgical History				
			0.00	1.00			No	0.00
3	Age	4.00	**No Risk**	**Applicable Risk**			**Recorded Age**	**Resultant Score**
			< 55 years old	≥ 55 years old				
			0.00	1.00			50	0.00
							Total Score	6.00
							Number of Risk Factors Used	1

A comparison was then performed between the results and the combined information of the hazard analysis and incident rates (Table 4-58). As stated previously in the Incident Rate Data section from earlier in this chapter, incident rate results for each observation are not specific for the task that was observed but instead, for the general work area of the task. So while they are a good general indicator of high risk locations, they have to be supplemented with the addition of the subject matter expert judgments from the task hazard analysis. These 17 hazard judgments include 7 tasks labeled hazardous and 10 labeled safe. The number of risk factors per observation range from 1 to 4 with a mean of 1.94 risk factors per task. Individual risk resultant scores for each task observation ranged from 1.50 to 5.50 with a mean of 2.87 per task.

When we group the tasks by the results of the hazard analysis subject matter experts (previously shown in Table 4-25), we form two groups; one for safe and one for hazardous. Seven of the 17 observations are shown to be hazardous and 10 are safe. Hazardous occupational resultant scores range from 2.75 to 5.50 (mean = 3.68), whereas safe are from 1.5 to 3.0 (mean = 2.30). Notice that a division between the two groups begins forming around the scores of 2.75 and 3.0. Two safe observations had scores of 3.0 (observations 10 and 16). One observation (# 13) had a score of 2.75 and was labeled as hazardous. Now obviously a hazardous score cannot be lower than a safe score as the tool functions on higher scores consisting of more risk than lower scores. This means that more detailed evaluation needs to be done from the perspective of the individual risk factors triggered within each task.

Table 4-58 Cross comparison between initial model results, hazard analysis, and incident rates

Observation #	Task #	Participant #	Model Calculated Occupational Resultant Scores	Number of Risk Factors Considered	Hazard Analysis Consensus	Task Area Incident Rate (OSHA Recordable)
1	1	1	1.50	1	Safe	6.1
2	2	1	5.50	4	Hazardous	6.1
3	3	1	4.00	3	Hazardous	6.1
4	4	2	3.00	2	Hazardous	6.1
5	5	8	2.50	2	Safe	5.5
6	6	8	2.50	2	Safe	5.5
7	6	7	2.50	2	Safe	5.5
8	7	8	2.50	2	Safe	5.5
9	6	6	2.50	2	Safe	5.5
10	8	3	3.00	2	Safe	3.8
11	9	4	3.00	2	Hazardous	3.8
12	10	4	3.00	2	Hazardous	3.8
13	11	9	2.75	2	Hazardous	4.1
14	12	9	4.50	1	Hazardous	4.1
15	13	5	1.50	1	Safe	3.8
16	14	5	3.00	2	Safe	3.8
17	15	5	1.50	1	Safe	3.8

With this information now available for comparison, the model was then checked for what this study calls false positives. False positives are risk factors that were triggered by the model due to them surpassing at least the minimal threshold from the risk multipliers portion yet would not be judged as hazardous. So for example, if one looks at kneeling risks, the way the model currently stands, if someone were to kneel for at least one second, then the model will consider it as a minimal risk and assign it a risk score. Meanwhile participants who kneel for 25 minutes are also assigned the same minimal risk score. So for observations like numbers 10 and 16 who have hazardous labels of safe, it was a good idea to take a meticulous look at what initiated their scores.

Additionally, we can also call on the limited help from the task area incident rates. For example, observations 5 – 10 all have hazard classifications of safe, even though their task area incident rates are at 5.5. When we look at their risk scores from the model, they result in the range of 2.50 – 3.00. The number of risk factors triggered by the model for each of these observations is 2. By looking at the multiplier threshold levels for each of the risk factors triggered, we were able to reduce the sensitivity of the model which reduced the number of false positives. The results of this modification to the knee model are given further detail in the Second Iteration section of this Validation Testing section of Chapter Four.

Second Iteration Test Results

The drive to remove false positives from the model required de-sensitizing the trigger mechanisms of the model itself. Minimal risk levels of the multiplier threshold areas of the model were changed so that minimum risk categorization would require at least 1 minute (kneeling, squatting/crouching, crawling, and prolonged knee contact stress) or 1 stair/ladder flight of risk exposure for each appropriate category. This minute change dramatically affected the task occupational resultant scores. Table 4-59 although similar in structure to Table 4-35, displays an overview of this change in occupational risk information and its application to each of the nine participants and their associated task observations. Tables 4-60 – 4-70 displays the detailed occupational risk information from each of their observed tasks. Note that personal risks have not changed since they are intrinsic to the individuals themselves. Thus, only the occupational risk information has been adjusted for sensitivity.

Participant 1, while exposed to several risk factors (kneeling, squatting/crouching, crawling, stair/ladder climbing, and walking/standing), was only found by the knee risk model to be at risk for the kneeling related activity that was observed over the three tasks (Table 4-60). This amounted to an occupational resultant score of 1.50 (Table 4-61).

Participant 2 was only found to be at risk for kneeling related postures, as his exposure to squatting/crouching and walking/standing risks were not considered to be high enough of a threat by the model. This resulted in an occupational resultant score of 1.50 (Table 4-62).

Participant 3's exposure to four risk factors (kneeling, squatting/crouching, lifting/carrying, and walking/standing) were found to only trigger the risk model for two variables. These were kneeling and squatting/crouching. The resulting total for these occupational risks was 3.00 (Table 4-63).

The three risk factors that participant 4 was exposed to included kneeling, squatting/crouching, and walking/standing. Walking/standing was not included in the knee model calculation because it did not meet the two hour risk requirement. This resulting occupational risk score was 6.00 (Table 4-64 – 4-65).

Table 4-59 Participant resultant occupational and personal scores for the second validation iteration

Observation #	Task #	Participant #	Model Calculated Total Occupational Resultant Score	Number of Occupational Risk Factors Considered	Model Calculated Personal Resultant Score	Number of Personal Risk Factors Considered
1	1	1	1.50	1	12.00	2
2	2					
3	3					
4	4	2	1.50	1	0.60	1
10	8	3	3.00	2	0.60	1
11	9	4	6.00	2	4.50	1
12	10					
15	13	5	1.50	1	10.50	2
16	14					
17	15					
9	6	6	0.00	0	0.00	0
7	6	7	1.00	1	0.00	0
5	5	8	1.00	1	6.00	1
6	6					
8	7					
13	11	9	4.50	2	6.00	1
14	12					

Participant number 5 was exposed to the same types of risk factors as was participant 4 (kneeling, squatting/crouching, and walking/standing). Kneeling was the only risk considered by the model and that risk factor was only acknowledged for two of the three observed tasks. This summed to an occupational resultant score of 1.50 (Table 4-66-4-67).

The three types of risk variables that participant 6 was exposed to were squatting/crouching, stair/ladder climbing, and walking/standing. None of these variables were triggered in the minimum requirements for risk by the model. This resultant score was 0.00 (Table 4-68). Participant 6 was also the only subject to be found to have no occupational or personal risk towards knee disorders.

Participant 7 was exposed to three risk factors during his one task observation (squatting/crouching, stair/ladder climbing and walking/standing). After the model modification, the number of applicable risk variables was reduced to one (stair/ladder climbing). The occupational resultant score was 1.00 (Table 4-69).

Participant 8 was also exposed to squatting/crouching, stair/ladder climbing, and walking/standing tasks. His results were the same as participant 7 in that only stair/ladder climbing was applicable to his situation. His occupational resultant score over the three task observations was also 1.00 (Table 4-70 – 4-71).

Participant 9's risk factors included kneeling, walking/standing, and prolonged knee contact stress (Table 4-72). With only kneeling being considered as a moderate risk, the occupational resultant score was reduced to 4.50.

Table 4-60 Second iteration of participant #1's occupational risk results per task observed

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Task #2		Task #3	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day						
			1.00	0.75	0.25	0:01:35	1.50	0:07:19	1.50	0:11:35	1.50
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day						
			1.00	0.75	0.25			0:00:04	0.00	0:00:03	0.00
3	Crawling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day						
			1.00	0.75	0.25			0:00:22	0.00		
4	Stair or Ladder Climbing	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**
			> 15 flights per day	10-15 flights per day	≥ 1 flight; < 10 flights per day						
			1.00	0.50	0.25			0.55	0.00	0.06	0.00

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers		Task #1		Task #2		Task #3	
			No Risk	**Applicable Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
6	Walking and/or Standing	2.00	< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing			0:04:07	0.00	0:00:31	0.00
			0.00	1.00						
					Total	1.50		1.50		1.50
					Number of Risk Factors Used	1		1		1

Table 4-61 Second iteration of Participant #1's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Total Risk	
1	Kneeling	6.00	High Risk	Moderate Risk	Minimal Risk	Recorded Duration	Resultant Score
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day		
			1.00	0.75	0.25	0:20:29	1.50
2	Squatting or Crouching	6.00	High Risk	Moderate Risk	Minimal Risk	Recorded Duration	Resultant Score
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day		
			1.00	0.75	0.25	0:00:07	0.00
3	Crawling	6.00	High Risk	Moderate Risk	Minimal Risk	Recorded Duration	Resultant Score
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day		
			1.00	0.75	0.25	0:00:22	0.00
4	Stair or Ladder Climbing	4.00	High Risk	Moderate Risk	Minimal Risk	Recorded Count	Resultant Score
			> 15 flights per day	10-15 flights per day	≥ 1 flight; < 10 flights per day		
			1.00	0.50	0.25	0.61	0.00

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Total Risk	
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing			
			0.00	1.00		0:04:38	0.00
						Total	1.50
						Number of Risk Factors Used	1

Table 4-62 Second iteration of Participant #2's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Total Risk	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	0:01:04	1.50	0:01:04	1.50
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	0:00:31	0.00	0:00:31	0.00
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing					
			0.00	1.00		0:02:08	0.00	0:02:08	0.00
						Total	1.50		1.50
						Number of Risk Factors Used	1		1

Table 4-63 Second iteration of Participant #3's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Total Risk	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	0:24:21	1.50	0:24:21	1.50
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	0:04:26	1.50	0:04:26	1.50
5c	Lifting/carrying ≥ 22 lbs per item (**Moderately Heavy**)	3.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**
			> 50 times per work day	40-50 times per work day	20-40 times per work day				
			1.00	0.75	0.50	3	0.00	3	0.00
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing					
			0.00	1.00		0:13:19	0.00	0:13:19	0.00
						Total	3.00		3.00
						Number of Risk Factors	2		2

Table 4-64 Second iteration of Participant #4's occupational risk results per task observed

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Task #2	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	0:04:24	1.50	0:27:14	1.50
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	0:00:02	0.00	0:01:53	1.50
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing					
			0.00	1.00		0:02:03	0.00	0:31:18	0.00
						Total	1.50		3.00
						Number of Risk Factors Used	1		2

Table 4-65 Second iteration of Participant #4's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Total Risk	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day		
			1.00	0.75	0.25	0:31:38	4.50
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day		
			1.00	0.75	0.25	0:01:55	1.50
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing			
			0.00	1.00		0:33:21	0.00
						Total	6.00
						Number of Risk Factors Used	2

Table 4-66 Second iteration of Participant #5's occupational risk results per task observed

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Task #2		Task #3	
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
1	Kneeling	6.00	> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day						
			1.00	0.75	0.25	0:07:21	1.50	0:00:33	0.00	0:02:17	1.50
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
2	Squatting or Crouching	6.00	> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day						
			1.00	0.75	0.25			0:00:04	0.00		
			No Risk	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
6	Walking and/or Standing	2.00	< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing							
			0.00	1.00		0:00:15	0.00	0:01:49	0:00:00		
						Total	1.50		0.00		1.50
						Number of Risk Factors Used	1		0		1

Table 4-67 Second iteration of Participant #5's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Total Risk	
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
1	Kneeling	6.00	> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day		
			1.00	0.75	0.25	0:10:11	1.50
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
2	Squatting or Crouching	6.00	> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day		
			1.00	0.75	0.25	0:00:04	0.00
			No Risk	**Applicable Risk**		**Recorded Duration**	**Resultant Score**
6	Walking and/or Standing	2.00	< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing			
			0.00	1.00		0:02:04	0.00
						Total	1.50
						Number of Risk Factors Used	1

Table 4-68 Second iteration of Participant #6's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Total Risk	
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
2	Squatting or Crouching	6.00	> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	0:00:06	0.00	0:00:06	0.00
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**
4	Stair/Ladder Climbing	4.00	> 15 flights per day	10-15 flights per day	≥ 1 flight; < 10 flights per day				
			1.00	0.50	0.25	0.61	0.00	0.61	0.00
			No Risk	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
6	Walking and/or Standing	2.00	< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing					
			0.00	1.00		0:02:06	0.00	0:02:06	0.00
						Total	0.00		0.00
						Number of Risk Factors Used	0		0

Table 4-69 Second iteration of Participant #7's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Total Risk	
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	0:00:47	0.00	0:00:47	0.00
4	Stair/Ladder Climbing	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**
			> 15 flights per day	10-15 flights per day	≥ 1 flight; < 10 flights per day				
			1.00	0.50	0.25	3.64	1.00	3.64	1.00
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing					
			0.00	1.00		0:38:13	0.00	0:38:13	0.00
						Total	1.00		1.00
						Number of Risk Factors Used	1		1

Table 4-70 Second iteration of Participant #8's occupational risk results per task observed

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Task #2		Task #3	
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day						
			1.00	0.75	0.25	0:00:10	0.00	0:00:31	0.00	0:00:04	0.00
4	Stair/ Ladder Climbing	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 15 flights per day	10-15 flights per day	≥ 1 flight; < 10 flights per day						
			1.00	0.50	0.25	2.36	1.00	3.82	1.00	2.18	1.00
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing							
			0.00	1.00		0:21:43	0.00	0:20:52	0:00:00	0:28:33	0.00
						Total	1.00		1.00		1.00
						Number of Risk Factors Used	1		1		1

Table 4-71 Second iteration of Participant #8's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Total Risk	
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day		
			1.00	0.75	0.25	0:00:45	0.00
4	Stair/Ladder Climbing	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**
			> 15 flights per day	10-15 flights per day	≥ 1 flight; < 10 flights per day		
			1.00	0.50	0.25	8.36	1.00
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**		**Recorded Duration**	**Resultant Score**
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing			
			0.00	1.00		1:11:08	0.00
						Total	1.00
						Number of Risk Factors Used	1

Table 4-72 Second iteration of Participant #9's total occupational risk results

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Task #2		Total Risk	
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
1	Kneeling	6.00	> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day						
			1.00	0.75	0.25	0:05:14	1.50	0:32:57	4.50	0:38:11	4.50
			No Risk	**Applicable Risk**		**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
6	Walking and/or Standing	2.00	< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing							
			0.00	1.00		0:22:10	0.00	1:24:03	0:00:00	1:46:13	0.00
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
8	Prolonged contact stress against the patella bone other than when kneeling	5.00	> 1 hr per work day	0.5-1 hrs per work day	≥ 1 min; < 0.5 hrs per work day						
			1.00	0.75	0.25	0:00:29	0.00			0:00:29	0.00
						Total	1.50		4.50		4.50
						Number of Risk Factors Used	2		1		2

Table 4-73 gives an overview of the second iterations results of the model and how the scores compare to the hazard analysis and the incident rates. While the personal resultant scores remain unchanged, the occupational ones have been reduced. Now it seems that more of the resultant scores such as 1.50 are found in both the safe (observations 1, 15, and 17) and hazardous regions (2, 3, 4, 11, and 13). This is due to the changes that were made to the occupational portion of the model for removing false positives. This resulting overlap and its explanations will be clarified more in Chapter Five's Hazard Analysis versus Model Results section. This false positive removal process was a necessary evolution of the model's progress as we cannot have just brief exposure (< 1 minute or < 1 stair flight) raise a false hazard. The only exception to this would be from a cumulative perspective where a worker's work day may consist of a multitude of short repetitive tasks that have short exposures. In this case, it is suggested that the model be utilized from a cumulative versus a task perspective.

A breakdown of the observations that were labeled as safe and hazardous shows that safe tasks now have a range of 0 to 3.00 (mean = 1.15). Hazardous tasks have a mean of 2.14 and a range from 1.50 to 4.50.

Table 4-73 Cross comparison between model results (second iteration), hazard analysis, and incident rates

Observation #	Task #	Participant #	Model Calculated Occupational Resultant Scores	Number of Risk Factors Considered	Hazard Analysis Consensus	Task Area Incident Rate (OSHA Recordable)
1	1	1	1.50	1	Safe	6.1
2	2	1	1.50	1	Hazardous	6.1
3	3	1	1.50	1	Hazardous	6.1
4	4	2	1.50	1	Hazardous	6.1
5	5	8	1.00	1	Safe	5.5
6	6	8	1.00	1	Safe	5.5
7	6	7	1.00	1	Safe	5.5
8	7	8	1.00	1	Safe	5.5
9	6	6	0.00	0	Safe	5.5
10	8	3	3.00	2	Safe	3.8
11	9	4	1.50	1	Hazardous	3.8
12	10	4	3.00	2	Hazardous	3.8
13	11	9	1.50	1	Hazardous	4.1
14	12	9	4.50	1	Hazardous	4.1
15	13	5	1.50	1	Safe	3.8
16	14	5	0.00	0	Safe	3.8
17	15	5	1.50	1	Safe	3.8

Final Iteration Test Results

SPSS Results for Initial Iteration

As mentioned in the Data Analysis portion of Chapter Three's Methodology, a non-parametric Mann-Whitney Test was used to see if the tasks deemed by subject matter experts as hazardous or safe were significantly different from each other in their distribution. Figure 4.1 displays the results of the initial model's test showing that occupational resultant scores between these two groups were significantly different in their mean ranks and their sum of ranks ($U = 5.00$, $p = 0.002$). This rejection of the null hypothesis verifies that the occupational resultant scores for the hazardous tasks are in fact higher than scores for the safe task group. Additional data from this Mann Whitney U test of the first iteration can be seen in Appendix D.

Mann-Whitney Test

Ranks

	Task Grouping	N	Mean Rank	Sum of Ranks
Risk Scores	Safe Group	10	6.00	60.00
	Hazardous Group	7	13.29	93.00
	Total	17		

Test Statistics[b]

	Risk Scores
Mann-Whitney U	5.000
Wilcoxon W	60.000
Z	-3.010
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.002[a]

a. Not corrected for ties.

b. Grouping Variable: Task Grouping

Figure 4.1 Mann-Whitney Test results for the initial version of the knee risk assessment model

SPSS Results for Second Iteration

The same Mann-Whitney Test was utilized again after the model was modified to remove false positives. Figure 4.2 illustrates that there is a significant difference between the distributions of both the hazardous and safe groups ($U = 13.00$, $p = 0.033$). Higher mean rank and sum of ranks for the hazardous group are a depiction of the notion that as risk increases the occupational resultant score increases as well. Supplementary data from this test can be seen in Appendix D's Mann-Whitney U test of the model's second iteration.

Mann-Whitney Test

Ranks

	Task Grouping	N	Mean Rank	Sum of Ranks
Risk Scores	Safe Group	10	6.80	68.00
	Hazardous Group	7	12.14	85.00
	Total	17		

Test Statistics[b]

	Risk Scores
Mann-Whitney U	13.000
Wilcoxon W	68.000
Z	-2.286
Asymp. Sig. (2-tailed)	.022
Exact Sig. [2*(1-tailed Sig.)]	.033[a]

a. Not corrected for ties.

b. Grouping Variable: Task Grouping

Figure 4.2 Mann-Whitney Test results for the second version of the knee risk assessment model

Results for Gold Standard Comparisons

Moore and Garg (1995) noted that for their study they defined a hazardous threshold for their Strain Index tool at 5 or greater. Similar in approach, it was decided to search for where a threshold may lie between this safe and hazardous barrier. After studying the risk scores, a proposed risk threshold was made for hazardous tasks with a value of 2.0 or greater. This decision was made for two reasons; 1) the score of 1.50 was the lowest score noticed between safe and hazardous tasks and 2) the value of 2.0 represents the lowest possible moderate (stair/ladder climbing) or applicable (walking/standing) occupational risk resultant score. Tasks having values lower than this would represent safe tasks. Tasks at 2.0 or higher are hazardous tasks (Table 4-74).

Table 4-74 Cross comparison between model results of the second iteration (including risk level), hazard analysis, and incident rates

Observation #	Task #	Participant #	Model Calculated Occupational Resultant Scores	Model Calculated Occupational Risk Levels	Hazard Analysis Consensus	Task Area Incident Rate
1	1	1	1.50	Safe	Safe	6.1
2	2	1	1.50	Safe	Hazardous	6.1
3	3	1	1.50	Safe	Hazardous	6.1
4	4	2	1.50	Safe	Hazardous	6.1
5	5	8	1.00	Safe	Safe	5.5
6	6	8	1.00	Safe	Safe	5.5
7	6	7	1.00	Safe	Safe	5.5
8	7	8	1.00	Safe	Safe	5.5
9	6	6	0.00	Safe	Safe	5.5
10	8	3	3.00	Hazardous	Safe	3.8
11	9	4	1.50	Safe	Hazardous	3.8
12	10	4	3.00	Hazardous	Hazardous	3.8
13	11	9	1.50	Safe	Hazardous	4.1
14	12	9	4.50	Hazardous	Hazardous	4.1
15	13	5	1.50	Safe	Safe	3.8
16	14	5	0.00	Safe	Safe	3.8
17	15	5	1.50	Safe	Safe	3.8

Using the same hazard evaluations from our subject matter experts, we can now compare the tool to their judgments. This is similar to a gold standard comparison where we base our model on the word of the subject matter experts. Sensitivity of the model can be used to test for true hazardous model evaluations. It is calculated by dividing the hazardous labeled observations from the model by the hazardous labeled observations by the subject matter experts (2/7). This produces a low sensitivity of 0.285. The same can be said of true safe model evaluations (specificity) which compares the number of safe model evaluations to the number of the hazard analysis subject matter expert (safe) evaluations (this equals 9/10). The specificity of the current version of this knee risk model is at 0.90 which can be considered fairly high. So based on this evaluation of sensitivity and specificity, the tool is quite capable of detecting 90% of the safe tasks but at the moment only capable of detecting 28.5% of hazardous tasks.

A gold standard statistical comparison was also made between the model evaluation and the hazard analysis (one sample Student's t Test for unequal variances). The results (Appendix D's t Test) showed no significant difference between the two groups ($t(34) = 1.512$, $p = 0.156$). So in other words, the test did not reject the null hypothesis (for equal means).

Worst Case Scenarios

The results that have been discussed so far deal with the data that was collected from the aircraft manufacturer's sample plant location. A review of each of the tasks gives a general idea, that from a task perspective, a majority of the observations are considered to be safe by the knee risk model (14 of 17 observations). The number of risk factors exposed to per observation ranged between 1 and 2 with a mean of 1. The highest occupational resultant risk score was 4.50. It was decided that a set of worst case scenarios should be run so that the effect of the model can be investigated from a more hazardous perspective. Three scenarios were run by the model. These involved a hypothetical task that required carpet installation, lifting/carrying/lowering task exposures for a beverage delivery driver, and what was called a minimal risk flare-up (where several minimal risks just passing risk criteria were set off by the model).

A quick literature review of tasks involving carpet laying, found that kneeling as a risk, consumed anywhere from 3 hours per work day (Kivimaki et al., 1992) to 4.5 hours or

56% of an eight hour shift (Jensen, Mikkelsen, Loft, & Eenberg, 2000). Kivimaki et al., 1992) adds that approximately 15 minutes of a carpet layer's day may have to do with squatting (3%). The use of a knee kicking tool for stretching carpets flush against a wall is unique to carpet laying. WISHA (Washington State Legislature, 2000) placed a high level recommendation for knee kicking at once per minute for more than two hours per day (> 120 per day). In addition to these known risks, was added a hypothetical one (crawling).

Table 4-75 displays the information pertaining to our carpet layer. This task consisted of four risk factor exposures. Just over 3 hours of work was made up by kneeling risks, 15 minutes included squatting/crouching, 13 minutes for crawling, and 125 knee impacts. The occupational resultant score of the task was 16.00. At this score, the task was deemed to have a risk level of hazardous. From the personal perspective of the worker (Table 4-76), all three risk factors were triggered. His BMI score was 36, he had a past knee injury (prepatellar bursitis), and he was 56. This produced a personal resultant score of 16.00 also.

Table 4-75 Occupational risk assessment of a hypothetical worst case scenario involving carpet laying

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Total Risk	
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	3:01:35	6.00	3:01:35	6.00
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	0:15:00	1.50	0:15:00	1.50
3	Crawling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥ 1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	0:13:00	1.50	0:13:00	1.50

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Total Risk	
			No Risk	Applicable Risk		Recorded Count	Resultant Score	Recorded Count	Resultant Score
7	Using the knee as a hammer	7.00	< 20 impacts per day	≥ 20 impacts per day					
			0.00	1.00		125	7.00	120	7.00
						Total	16.00		16.00
						Number of Risk Factors Used	4		4
						Risk Level	Hazardous		Hazardous

Table 4-76 Personal risk assessment of a hypothetical worst case scenario involving carpet laying

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers				Total Risk	
1	Body Mass Index	6.00	**High Risk**	**Moderate Risk**	**Low Risk**	**No Risk**	**Recorded BMI**	**Resultant Score**
			> 35	30-35	25-29.9	< 25		
			1.00	0.75	0.10	0.00	36	6.00
2	Past Knee Injury or Surgery	6.00	**No Risk**	**Applicable Risk**			**Recorded Past Injury**	**Resultant Score**
			No Injury History	Injury or Surgical History				
			0.00	1.00			Yes	6.00
3	Age	4.00	**No Risk**	**Applicable Risk**			**Recorded Age**	**Resultant Score**
			< 55 years old	≥ 55 years old				
			0.00	1.00			56	4.00
							Total Score	16.00
							Number of Risk Factors Used	3

Tables 4-77 to 4-78 contain information relating to the beverage delivery driver. For this situation, two tasks were considered. Both involved the lifting/carrying risk. McGlothlin (1996) talks about the type of material that is handled by soft drink delivery drivers. Items include anything from lids, to drink cases full of glass bottles or cans, to 2-liter cases, to the wooden pallets themselves. Depending on the items handled, object weights can be as light as 7 pound lids to as heavy as 16-ounce returnable glass bottle cases (24 bottles in each case) at 57.5 pounds. For the purposes of this scenario, we looked at a 24 aluminum can 12 –ounce soft drink case (22 pounds) for task 1's moderately heavy category and a 24 glass 20-ounce soft drink case (57.5 pounds) for task 2's heavy category. Using data from McGlothlin's (1996) study, the frequency rate was calculated to be at 6 lifts per minute. At exposure durations of 40 to 45 minutes (McGlothlin mentioned < 1 hour), we see counts at 240 and 270, respectively. These risks produce a hazard of 3.00 for task 1 (hazardous) and 4.00 for task 2 (also hazardous). This combined exposure count would now be 510. The cumulative risk to the individual from work related tasks is a resultant score of 4.00 and a risk level of hazardous. As was pointed out earlier in this chapter's Final Model Results, when multiple lifting/carrying categories are assessed cumulatively across several tasks, then the mean weight of all the handled objects determines which subset will be used. The only exception to this is when multiple lifting/carrying tasks trigger high risk categories from varying subsets. For these instances, assume that the subset to choose will be the one for the heaviest weight subset (extremely heavy, heavy, and moderately heavy). So for the example given, the chosen subset was heavy for the high risk category. This scenario's personal resultant score of 0.60 is due to the BMI risk factor being triggered (BMI = 26).

Table 4-77 Occupational risk assessment of a hypothetical worst case scenario involving beverage delivery loading and unloading

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Task #2		Total Risk	
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**
5b	Lifting/ carrying ≥ 55 lbs per item **(Heavy)**	4.00	> 30 times per work day	20-30 times per work day	10-20 times per work day						
			1.00	0.75	0.50			270	4.00	510	4.00
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**
5c	Lifting/ carrying ≥ 22 lbs per item (Moderately Heavy)	3.00	> 50 times per work day	40-50 times per work day	20-40 times per work day						
			1.00	0.75	0.50	240	3.00			240	NA
						Total	3.00		4.00		4.00
						Number of Risk Factors Used	1		1		1
						Risk Level	Hazardous		Hazardous		Hazardous

NA = Not Applicable

Table 4-78 Personal risk assessment of a hypothetical worst case scenario involving beverage delivery loading and unloading

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers				Total Risk	
1	Body Mass Index	6.00	**High Risk**	**Moderate Risk**	**Low Risk**	**No Risk**	**Recorded BMI**	**Resultant Score**
			> 35	30-35	25-29.9	< 25		
			1.00	0.75	0.10	0.00	26	0.60
2	Past Knee Injury or Surgery	6.00	**No Risk**	**Applicable Risk**			**Recorded Past Injury**	**Resultant Score**
			No Injury History	Injury or Surgical History				
			0.00	1.00			No	0.00
3	Age	4.00	**No Risk**	**Applicable Risk**			**Recorded Age**	**Resultant Score**
			< 55 years old	≥ 55 years old				
			0.00	1.00			26	0.00
							Total Score	0.60
							Number of Risk Factors Used	1

Table 4-79 illustrates what would happen in the event that multiple occupational risk factors are triggered for one task evaluation. When all of the risk factors triggered are for minimal risks, it is nicknamed *minimal risk flare-up*. The table depicts a situation in which 6 risk factors (kneeling, squatting/crouching, crawling, stair/ladder climbing, lifting/carrying for the extremely heavy subset, and prolonged knee contact stress) are activated by just surpassing the minimal criteria for the minimal risk category. The tool currently functions by adding together all of the resultant scores for each risk factor into a resultant total score. For the occupational risk assessment, resultant scores of at least 2.0 or greater are given the risk level of hazardous (even though the individual risk factors themselves are all minimal categories). So in the case of this minimal risk flare-up scenario, the occupational resultant score is 9.25 and considered as hazardous for the risk level. This is discussed more in the Discussion section of Chapter Five under the Study Limitations.

Table 4-79 Occupational risk assessment of a hypothetical worst case scenario involving a minimal risk flare-up

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Total Risk	
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
1	Kneeling	6.00	> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	0:01:30	1.50	0:01:30	1.50
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
2	Squatting or Crouching	6.00	> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	0:01:30	1.50	0:01:30	1.50
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Duration**	**Resultant Score**
3	Crawling	6.00	> 1 hr per work day	0.5-1 hrs per work day	≥ 1 min; < 0.5 hrs per work day				
			1.00	0.75	0.25	0:01:30	1.50	0:01:30	1.50
			High Risk	**Moderate Risk**	**Minimal Risk**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**
4	Stair or Ladder Climbing	4.00	> 15 flights per day	10-15 flights per day	≥ 1 flight; < 10 flights per day				
			1.00	0.50	0.25	1.00	1.00	1.00	1.00

Risk Variable#	Risk Variable	Risk Weight	Risk Multipliers			Task #1		Total Risk	
5a	Lifting/ carrying ≥ 110 lbs per item (**Extremely Heavy**)	5.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Count**	**Resultant Score**	**Recorded Count**	**Resultant Score**
			> 10 times per work day	5-10 times per work day	1-5times per work day				
			1.00	0.75	0.50	1	2.00	1	2.00
8	Prolonged contact stress against the patella bone other than when kneeling	5.00	**High Risk**	**Moderate Risk**	**Minimal Risk**	**Recorded Duration**	**Resultant Score**	**Recorded Count**	**Resultant Score**
			> 1 hr per work day	0.5-1 hrs per work day	≥ 1 min; < 0.5 hrs per work day				
			1.00	0.75	0.50	0:01:30	1.25	0:01:30	1.25
						Total	9.25		9.25
						Number of Risk Factors Used	6		6
						Risk Level	Hazardous		Hazardous

CHAPTER FIVE : DISCUSSION

A plethora of knee risk factors were found to be associated with the three knee disorders of knee OA, meniscal cases, and bursitis. From these epidemiologically based risk factors, a risk assessment model was developed. This initial prototype version of a LERA model portion for the knee proved to be worthwhile as it has created a starting point for future work. While functional as is, additional studies need to test the results of the model so that it can continue to evolve. This process begins by first understanding how the model was developed and then creating solutions for its limitations into future derivatives.

Risk Factor Refinement

There were several risk factors that did not "make the cut" due to the judgments of the subject matter experts of the model development committee. Even though they were mentioned to be considered as risk factors in epidemiological literature, standing up from kneeling/squatting/crawling, chair sitting (while driving), vibration tool usage, and physically intense habits and hobbies were removed due to vagueness, low number of studies, or low statistical association with risk (when HR, RR, or OR 95% CI's included values ≤ 1.0).

Standing up from a low position is extremely common when working near the floor level of a work environment. Biomechanically, the committee knew that constantly lifting the body from near the floor level does stress the knee with physiological forces, but ergonomically, practitioners recommend that employees change static postures intermittently. So the act of standing up would cause a conflict with recommended ergonomic practice. In addition to this, the committee also acknowledged that squatting and kneeling risk factors inherently included the act of standing up from a low position. So the standing up risk would automatically be included after every squatting or kneeling exposure. It was due to this divergence that the risk factor was removed from the knee model for the time being.

Chair sitting while driving was another risk factor considered by this committee. It was only noted as a risk factor for meniscal disorders in just one study (Baker et al., 2002). So until further evidence is published, this risk factor was another variable put on hold and not included in the model.

Vibration tool usage was another risk factor mentioned by literature (Lau et al., 2000) to be associated to knee disorders. While it makes sense that vibration could possibly be a cause of knee morbidity, the committee felt that further details are necessary. For instance, vertical vibration is mentioned to resonate through the knee differently depending on whether the knee is flexed or extended (Chaffin et al., 1999). Chaffin's et al. (1999) review points out that this vertical frequency ranges from 2 Hz (knee flexed) to 20 Hz (knee fully extended). The authors continue by mentioning that 20 Hz is known to be within tool vibration frequencies. What is not mentioned by either Chaffin et al. (1999) or Lau et al. (2000) are the specific types of tools (such as hand sanders or jack hammers) that give off these frequencies. Additionally, further investigation is needed to see how frequencies affect the knee tissue horizontally (medio-laterally and anterior-posteriorly). It was due to this vagueness in the epidemiology that vibration was removed by the committee until further detail is available to re-establish it.

The committee also noted that physically intensive habits or hobbies such as sports activities are shown to have a relationship with cumulative knee disorders (see knee disorder literature in Chapter Two). Several reasons were given as to why these personal risk factors were eliminated. First was the level of exposure necessary for risk association to be established (such as 1 hour per day). Next was the extensive breadth of sports or non-work activities that can be seen as a risk. This latter reason is in addition to low memory recall, as many of the epidemiological studies are retrospective and may require participants to recall details such as these from segments of their past.

Following the risk factor vetting process, the initial version of the model resulting from the model development committee was shown to be foundationally based on the epidemiology of Chapter Two. Chapter Four's Final Model Results is a representation of this. These final model results became known as the initial iteration of the model that was shown in the Validation Testing of the same Chapter Four. After the sample site's data was run through the model, it was noticed that there were several risk factors triggered during task evaluations that were either less than one minute or less than one flight of stairs. The model assessed and ranked these risk exposures as equivalent to items of longer durations such as kneeling for 20 minutes. Risk factors such as these were labeled as false positives and the model was adjusted to screen for these. The second iteration of the model from Chapter Four's Validation Testing illustrates this difference in its results.

Tables 5-1 and 5-2 show this study's final form of the knee portion of the LERA model's occupational and personal variables. Occupational resultant scores can range from 0 to 41 (when the high risk for extremely heavy lifting/carrying is activated). The minimum to maximum range for the personal resultant score is 0 and 16, respectively. In addition to the risk resultant score for the occupational and personal assessments, the occupational evaluation received a risk level evaluation of safe or hazardous (based on the occupational risk resultant score).

Table 5-1 Final knee risk assessment model view of the occupational risk assessment portion

Risk Var.#	Risk Variable	Risk Weight	Risk Multipliers		
1	Kneeling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day
			1.00	0.75	0.25
2	Squatting or Crouching	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day
			1.00	0.75	0.25
3	Crawling	6.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day
			1.00	0.75	0.25
4	Stair or Ladder Climbing	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 15 flights per day	10-15 flights per day	≥ 1 flight; < 10 flights per day
			1.00	0.50	0.25
5a	Lifting or carrying ≥ 110 lbs per item (**Extremely Heavy**)	5.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 10 times per work day	5-10 times per work day	1-5 times per work day
			1.00	0.75	0.50
5b	Lifting or carrying ≥ 55 lbs per item (**Heavy**)	4.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 30 times per work day	20-30 times per work day	10-20 times per work day
			1.00	0.75	0.50
5c	Lifting or carrying ≥ 22 lbs per item (**Moderately Heavy**)	3.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 50 times per work day	40-50 times per work day	20-40 times per work day
			1.00	0.75	0.50
6	Walking and/or Standing	2.00	**No Risk**	**Applicable Risk**	
			< 2 hrs walking and/or standing	≥ 2 hrs walking and/or standing	
			0.00	1.00	

Risk Var.#	Risk Variable	Risk Weight	Risk Multipliers		
7	Using the knee as a hammer	7.00	**No Risk**	**Applicable Risk**	
			< 20 impacts per day	≥ 20 impacts per day	
			0.00	1.00	
8	Prolonged contact stress against the patella bone other than when kneeling	5.00	**High Risk**	**Moderate Risk**	**Minimal Risk**
			> 1 hr per work day	0.5-1 hrs per work day	≥1 min; < 0.5 hrs per work day
			1.00	0.75	0.25

Table 5-2 Final knee risk assessment model view of the personal risk assessment portion

Risk Var.#	Risk Variable	Risk Weight	Risk Multipliers			
1	Body Mass Index	6.00	**High Risk**	**Moderate Risk**	**Low Risk**	**No Risk**
			> 35	30-35	25-29.9	< 25
			1.00	0.75	0.10	0.00
2	Past Knee Injury or Surgery	6.00	**No Risk**	**Applicable Risk**		
			No Injury History	Injury or Surgical History		
			0.00	1.00		
3	Age	4.00	**No Risk**	**Applicable Risk**		
			< 55 years old	≥ 55 years old		
			0.00	1.00		

Hazard Analysis versus Model Results

The low sensitivity level of the model's risk level assessment portion revealed a gap between the model's results and the results of the hazard analysis (see Chapter Four's Gold Standard Comparisons). Further investigation showed that this disconnect occurred due to the subject matter experts (through no fault of their own) not evaluating the minute intricacies as the model did, but instead judging the high level cumulative trauma perspective. So in other words, while the model assessed exposure counts and durations of a task, subject matter experts were more than likely judging types of risk factors observed, general occurrence levels, and possibly risk exposure over a prolonged duration of time (months and years). Additionally, the model's second iteration in evolution was adjusted for removing false positives or risk exposures less than one minute or less than one stair flight. A second evaluation by the subject matter experts for the hazard analysis was not completed to account for this latter fine-tuning. So while not as drastic as the analogy of comparing apples to oranges, this situation would instead actually be more like comparing oranges to tangerines. Future investigations for this model can account for this issue by making subject matter experts aware of the minimal risk levels of this knee risk assessment model so that task observational results are equally comparable.

The Evaluation of Worst Case Scenarios

The results of this study found that the sample site produced low risk values (occupational resultant scores and risk levels) for the number of observations taken. Because of this, worst case situations were developed so that the model could be evaluated for numerous risk factors with moderate to high categories of risk. As expected, the model reliably showed that the carpet laying, beverage handling, and minimal risk flare-up situations were all considered as hazardous to the people that performed them.

Study Limitations

Several limitations were noted from the results of this study. For example, although subject matter expert opinion was included from the hazardous analysis for the validation portion of the study, having an accurate incident rate per task would have been added value for the model result's risk legitimacy. This is something to be aware of for future studies, as higher incident rates typically are used to depict higher levels of risk for disorder development.

Data collection limitations should also be reflected on for future investigations. Unlike assessing work environments where workers are in a predetermined location the majority of the time, aircraft assembly requires numerous occasions of egress and ingress to and from the primary work location. This means that if your camera is stationary for the majority of the work observation, then you are missing tidbits of data outside the view of the camera. Many of these tasks required going to and from other work locations to gather tools or parts. This allowed additional task related exposure to risk factors such as stair climbing, walking, or lifting/carrying objects. One mitigation proposal for this might suggest the use of pedometers to capture task related walking distances. Note though that if the investigator is not aware of the travel plans of the participants, the pedometers could inadvertently capture both walking and stair climbing activities. Capturing a worker's true task related risk exposure levels though, will allow investigators a high level overview of the cumulative daily exposures that employees go through.

The minimal risk flare-up situation demonstrated in Chapter Four's Worst Case Scenarios section looks at how the model would react to multiple bare minimum risk exposures for several risk factors within a task. Circumstances such as this one will automatically trigger the model into evaluating the risk level for this task as hazardous rather than safe (due to the occupational resultant score being at least 2.0 or greater). Additional studies are needed to investigate this relationship among exposures to multiple risk factors during one task. One proposed method for multiple risk factor exposure is through the use of biomechanical studies which look at the individual physiological contributions from each postural activity. So for the time being, practitioners should thoroughly review the results of this model and each risk factor's exposure counts and durations and use their own professional judgment for overall task risk levels. This is especially true for when assessing total occupational resultant scores of multiple tasks involving minimal risk flare-ups over a period of time (such as a full work day).

CHAPTER SIX : CONCLUSION

This study was able to look at the lower extremity and see how understanding its risk related disorders may influence the future of industrial ergonomics. Without being specific to any one risk factor, the research gaps noted in Chapter One of this dissertation document can be made with the following general observations:

1. The LE is inadequately represented when it comes to occupational risk assessment for LE disorders
2. In addition to occupational risk factors, personal risk factors were also found to have a significant relationship with LE disorders, thus also needing to be accredited for risk

By looking at the knee as an initial location for developing a risk assessment model, the investigation was able to show that quantifying exposure to risk factors (both occupationally and personally) is mutually approachable and viable. As mentioned in Chapter Five, further validation of this knee risk assessment model needs to be done in the aerospace manufacturing environment and elsewhere. In addition to this, the model was not tested for between evaluator reliability, so this should also be considered for testing in the future. It is my hope that this study will be used as a starting point for increasing the awareness of occupational lower extremity disorders. It is also my hope that other regions of the body can be modeled in a similar manner to the knee. A likely starting point would be the hip for example, as the epidemiology for this area of the body has similar risk factors as the knee. Moreover, this would add an additional body location towards developing a full LERA model. The subsequent sub-sections of this chapter take a glimpse at possible derivatives of this study and the path of progression they can take. These glimpses include possible application methods and environments, task procedure variability, and task related risk factor loading and interaction.

Application Environments

This model is intended to assess both task related risk and cumulative occupational risk (multiple simultaneous or consecutive tasks) to the individual worker. Further study is needed to evaluate how effective the model is at assessing the cumulative whole day exposure for individuals. Instead of pinpointing specific high risk tasks at a workplace, a future study should consider following individuals for an entire work day, especially for environments where risk exposures are not consistently distributed (such as during highly repetitive tasks). Use of this objective will indirectly collect task related data as well (as each task will contribute to a participant's work day). This cumulative model produced data can then be contrasted against that of subject matter expert professional judgment. In addition, regardless of the future application environment, subject matter experts of the hazard analysis must be aware of how the risk assessment model functions so that both results are evenly comparable.

Worker Task Procedure Variability

On another interesting note, this study was able to collect data both unilaterally and bilaterally for each leg. This was due to recall ability access provided by a video recorded observation method. Supplementary studies should be provided to see if the model necessarily needs to be used to differentiate between left and right knee exposures.

Bilateral assessment is known to be employed in several currently available risk assessment tools that appraise the upper extremity's left and right portions (see Chapter Two's LE Analysis Screening Tools and Models). An example of a future study with this objective may be to investigate intra or inter subject observation of task completion procedures. Literature reviewed for this study did not provide any risk difference between the two lower limbs. Therefore, it would likely be that unless tasks restricted workers to use a particular knee, knee exposure (during kneeling, knee kicking, or prolonged knee contact stress) to the left, right, or both knee(s) would be subject to the preferences of the individual performing the task. In addition, if knee prevalence data is needed and if task information is captured in video format, then a simple duration comparison between the two knees would establish partiality for the individual and/or the task.

Task Risk Factor Loading and Interaction

A final area of research that could be derived from this study would be the concept of variable loading and/or interaction and their influence from a biomechanical perspective. To bring this to light, think of the biomechanics involved with each of these occupational risk factors. No two risk factors have the same biomechanical effect on the knee except possibly the kneeling and crawling variables. So it would be interesting to see if a future study could develop a taxonomy for each risk factor detailing the types and quantities of the forces involved. Then it may be possible to truly see how performing high exposure counts or long durations with several risk factors simultaneously or consecutively add to individual risk. With that biomechanical knowledge, the risk assessment model developed here can be further improved. One possible method to consider for implementing this improvement is through the use of fuzzy linguistic hedging (Chandramohan & Rao, 2006). This hedging method employs the ability to amplify the resultant scores depending on the number and/or type of risk factors activated by the model.

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The review performed by the designated IRB will meet the human subject protection requirements of Institution UCF's OHRP-approved FWA. The IRB at [redacted] will follow written procedures for reporting its findings and actions to the UCF Institutional Review Board, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246. Relevant minutes of IRB meetings will be made available to the UCF Institutional Review Board upon request. The UCF Institutional Review Board remains responsible for ensuring compliance with the IRB's determinations and with the Terms of its OHRP-approved FWA. This document must be kept on file by both parties and provided to OHRP upon request.

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Signature of Signatory Official ([redacted]):
[redacted] [signature] Date: 8/7/08 for E. Ihsler

Print Full Name: LAURA CAIN Institutional Title: Associate Medical Director

NOTE: The IRB of Institution A must be designated on the OHRP-approved FWA for Institution B.

Signature of Signatory Official (University of Central Florida):
[signature] Date: 7-23-2008

Print Full Name: Thomas O'Neal, Ph.D. Institutional Title: Associate Vice President for Research

APPENDIX C: DATA COLLECTION QUESTIONNAIRES

Occupational Lower Extremity Risk Assessment Modeling - The Knee – Model Development

SME Participant #: _____________

Occupational & Personal Risk Variables - Weight Association

Referring to the knee disorder guideline tables given in the *Appendix A* and the literature review segment of the disorders in *Appendix B*, for each risk variable listed (on the left side), fill in the strength of association (weight) to possible knee disorder (on right side) using whole numbers from the range 1-7 (1-weak association; 4-moderate association; 7-strong association).

Appendix C gives an example of a possible knee risk matrix that is composed of a participant's work day and includes totals of their cumulative "Subject Occupational Risk Score" as well as the occupation's "Task Risk Score". It is assumed that the personal variables are calculated separately of the occupational variables since they are subjective to the employee and employers cannot control them. The sum of the occupational and personal risk scores will lead to a "Total Risk Score" per person.

If you have any questions in reference to this document, feel free to contact me with either of the contact methods below:

Christopher Reid - PhD Candidate
McKnight Doctoral Fellow
Industrial Engineering & Management Systems -
Human Factors/Ergonomics
University of Central Florida
Email: creid@mail.ucf.edu

Weight Association Table

Variable #	Risk Variables	Metric Used	Occupational Risk	Personal Risk	Knee Disorder
1	Kneeling	Counts per day; Minutes/hours per 8 hr day	X		
2	Squatting or Crouching	Counts per day; Minutes/hours per 8 hr day	X		
3	Crawling	Counts per day; Minutes/hours per 8 hr day	X		
4	Stair/ladder climbing	Flights climbed per 8 hr day	X		
5	Lifting/carrying/moving ≥ 10 items per day	Counts per day; pounds per item	X		
6	Walking	Minutes/hours per 8 hr day; Miles per day	X		
7	Standing	Minutes/hours per 8 hr day	X		
8	Standing up from a kneel/squat/crawl	Counts per day	X		
9	Chair sitting (while driving)	Minutes/hours per 8 hr day	X		
10	Body Mass Index (BMI)	BMI score		X	
11	Past knee injury/surgery	Yes/No		X	
12	Age	Years		X	
13	Vibrating tools	Minutes/hours per 8 hr day	X		
14	Using the knee as a hammer	Yes/No	X		
15	Prolonged contact stress against the patella bone other than when kneeling	Counts per day; Minutes/hours per 8 hr day	X		
16	Physically intensive habits/hobbies that could affect the knee	Yes/No		X	

*Age is shown to be significant only in combination with kneeling, squatting, or stair climbing

Additional Weight Association Table

Variable #	Risk Variables	Metric Used	Occupational Risk	Personal Risk	Knee Disorder
17					
18					
19					
20					
21					

(Add additional risk variables here along with associated knee disorder weights under the Knee Disorder column)

Occupational & Personal Risk Variables - Multiplier Thresholds

Now based on what you mentioned as weights in the previous section, review again the guideline tables in Appendix A and the literature in Appendix B and consider how exposure quantities such as duration or count may affect how these individual variable weights would affect the overall risk. **Note that work days are considered by the references at 8hrs per day and 5 days per week**. These risk variable multipliers would be categorized according to the threshold levels of High, Moderate, Low, and No Risk. With that considered review the proposed thresholds below for each risk variable and contemplate whether the proposed multiplier ranges should be changed or remain the same. If you decide that change is needed for the risk variable multiplier, then indicate to what extent change is needed, where needs changing, and why.

1

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Standing up from a kneel/squat/crawl	> 30 times per work day	10-15 times per work day	10 times per work day	< 10 times per work day
Multiplier		1.00	0.50	0.25	0.00

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Standing up from a kneel/squat/crawl				
Multiplier					

2

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Standing	> 2 hrs per work day	1-2 hrs per work day	0.5-1 hr per work day	< 0.5 hrs per work day
Multiplier		1.00	0.50	0.25	0.00

*Times are accumulated throughout the multiple exposures of a work day

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Standing				
Multiplier					

3

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Stair/Ladder Climbing	> 30 flights per work day	15-30 flights per work day	10-14 flights per work day	< 10 flights per work day
Multiplier		1.00	0.50	0.25	0.00

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Stair/Ladder Climbing				
Multiplier					

4

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Crawling	> 2 hrs per work day	1-2 hrs per work day	0.5 -1 hr per work day	< 0.5 hrs per work day
Multiplier		1.00	0.50	0.25	0.00

*Times are accumulated throughout the multiple exposures of a work day. Consider crawling postures similar to kneeling postures with alternating weight distributions between hands and knees.

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Crawling				
Multiplier					

5

Risk Type	Risk Variable	Applicable Multiplier Quantity	Non-Applicable Multiplier Quantity
Occupational	Chair sitting (while driving) > 4 hrs / work day	Yes = 1	No = 0

Do you agree with the given risk variable multiplier relationship?
Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	Applicable Multiplier Quantity	Non-Applicable Multiplier Quantity
Occupational	Chair sitting (while driving) > 4 hrs / work day		

6

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Lifting/carrying/moving ≥ 10 items per work day	Avg. ≥ 110 lbs per item	Avg.=55-109 lbs per item	Avg.=22-54 lbs per item	Avg. < 22 lbs per item
Multiplier		1.00	0.50	0.25	0.00

*The number of times is accumulated throughout the multiple exposures of lifting during a work day. The references note that the time units are in weeks, for sake of standardization, we have gone with 10 per day instead. Additionally, each risk level is based on the average weight of all the items.

Do you agree with the given risk variable multiplier relationship?
Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Lifting/carrying/moving ???				
Multiplier					

7

Risk Type	Risk Variable	Applicable Multiplier Quantity	Non-Applicable Multiplier Quantity
Occupational	Using the knee as a hammer	Yes = 1	No = 0

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	Applicable Multiplier Quantity	Non-Applicable Multiplier Quantity
Occupational	Using the knee as a hammer		

8

Risk Type	Risk Variable	Applicable Multiplier Quantity	Non-Applicable Multiplier Quantity
Personal	Past knee injury/surgery	Yes = 1	No = 0

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	Applicable Multiplier Quantity	Non-Applicable Multiplier Quantity
Personal	Past knee injury/surgery		

9

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Squatting or Crouching	> 2 hrs per work day	1-2 hrs per work day	0.5 -1 hr per work day	< 0.5 hrs per work day
Multiplier		1.00	0.50	0.25	0.00

*Times are accumulated throughout the multiple exposures of a work day.

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Squatting or Crouching				
Multiplier					

10

Risk Type	Risk Variable	High Risk Activities	Moderate Risk Activities	Low Risk Activities	No Risk Activities
Personal	Physically intensive habits/hobbies that could affect the knee	Soccer; Rugby; Football; Running; Swimming; Martial arts; Gymnastics	Hiking; Biking;	Gardening	No physical hobbies/habits affecting the knee
Multiplier		1.00	0.50	0.25	0.00

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	High Risk Activities	Moderate Risk Activities	Low Risk Activities	No Risk Activities
Personal	Physically intensive habits/hobbies that could affect the knee				
Multiplier					

11

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Personal	BMI Score	> 35	30-35	25-29.9	<25
Multiplier		1.00	0.50	0.25	0.00

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Personal	BMI Score				
Multiplier					

12

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Walking	> 2 miles per work day	1-2 miles per work day	0.5 – 1 mile per work day	< 0.5 miles per work day
Multiplier		1.00	0.50	0.25	0.00

*Times are accumulated throughout the multiple exposures of a work day. Consider crawling postures similar to kneeling postures with alternating weight distributions between hands and knees.

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Walking				
Multiplier					

13

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Kneeling	> 2 hrs per work day	1-2 hrs per work day	0.5 -1 hr per work day	< 0.5 hrs per work day
Multiplier		1.00	0.50	0.25	0.00

*Times are accumulated throughout the multiple exposures of a work day.

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Kneeling				
Multiplier					

14

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Personal	Age	> 64	55-64	45-54 (women)	< 45 (women); < 55 (men)
Multiplier		1.00	0.50	0.25	0.00

*Age is shown to be significant only in combination with kneeling, squatting, or stair climbing

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Personal	Age				
Multiplier					

15

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Prolonged contact stress against the patella bone other than when kneeling	> 2 hrs per work day	1-2 hrs per work day	0.5 -1 hr per work day	< 0.5 hrs per work day
	Multiplier	1.00	0.50	0.25	0.00

*Times are accumulated throughout the multiple exposures of a work day. Consider these postures similar to kneeling postures with unknown quantities of compression against the front of the knee from leaning against work equipment or surfaces.

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Prolonged contact stress against the patella bone other than when kneeling				
	Multiplier				

16

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Use of vibration tools	> 2 hrs per work day	1-2 hrs per work day	0.5 -1 hr per work day	< 0.5 hrs per work day
Multiplier		1.00	0.50	0.25	0.00

*Although literature points to vibration tools, it is assumed that vibrating work surfaces of similar frequencies to tools that are in contact with the body also pose a risk.

Do you agree with the given risk variable multiplier relationship?

Yes☐ No☐

If No, then how would you format the proposed risk variable relationship below?

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Occupational	Use of vibration tools				
Multiplier					

Additional Occupational & Personal Risk Variables - Multiplier Thresholds

17

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Multiplier					

Which Industry, Job, or Task would this risk variable associate to?

___

___

18

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Multiplier					

Which Industry, Job, or Task would this risk variable associate to?

___

___

19

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Multiplier					

Which Industry, Job, or Task would this risk variable associate to?

___

___

20

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Multiplier					

Which Industry, Job, or Task would this risk variable associate to?

____

____

21

Risk Type	Risk Variable	High Risk Range	Moderate Risk Range	Low Risk Range	No Risk
Multiplier					

Which Industry, Job, or Task would this risk variable associate to?

____

____

Appendix A –Risk Variables and Knee Disorders

Table 1 The 16 risk variables associated to knee disorder

Risk Variables	Metric Used	Occupational Risk	Personal Risk	OA	Meniscal Disorder	Knee Bursitis	Knee Discomfort
Kneeling	Counts per day; Minutes/hours per 8 hr day	X		X	X	X	X
Squatting or Crouching	Counts per day; Minutes/hours per 8 hr day	X		X	X		X
Crawling	Counts per day; Minutes/hours per 8 hr day	X		X	X		
Stair/ladder climbing	Flights climbed per 8 hr day	X		X	X		
Lifting/carrying/moving	Counts per day; pounds per item	X		X	X		
Walking	Minutes/hours per 8 hr day; Miles per day;	X		X	X		
Standing	Minutes/hours per 8 hr day	X			X		
Standing up from a kneel/squat/crawl	Counts per day	X			X		
Chair sitting (while driving)	Minutes/hours per 8 hr day;	X			X		X
BMI	BMI score		X	X			
Past knee injury/surgery	Yes/No		X	X			
Age	Years		X	X			

Table 1 The 16 risk variables associated to knee disorder (continued)

Risk Variables	Metric Used	Occupational Risk	Personal Risk	OA	Meniscal Disorder	Knee Bursitis	Knee Discomfort
Vibrating tools	Minutes/hours per 8 hr day	X		X			
Using the knee as a hammer	Yes/No	X				X	
Prolonged contact stress against the patella bone other than when kneeling	Counts per day; Minutes/hours per 8 hr day	X				X	
Physically intensive habits/hobbies that could affect the knee	Yes/No;		X	X	X		

Table 2 Occupational knee risk variables associated to knee osteoarthritis (OR= Odds Ratio; 95% CI = 95% Confidence Interval)

Occupational Risk Type	Posture or Activity	Exposure Quantity	Statistical Measure	Source
Posture	Squatting	> 30 mins / work day	(OR = 6.9, 95% CI: 1.8,26.4)	Cooper, 1994
	Squatting	> 1 hr / work day	(OR = 2.3, 95% CI: 1.3,4.1)	Coggon, 2000
	Kneeling	> 30 mins / work day	(OR = 3.4, 95% CI: 1.3,9.1)	Cooper, 1994
	Kneeling	> 1 hr / work day	(OR = 1.8, 95% CI: 1.2,2.6)	Coggon, 2000
	Kneeling or squatting	> 2 hr / work day	(OR = 1.73, 95% CI: 1.13,2.66)	Manninen, 2002
Activity	Stair climbing	> 10 flights / work day	(OR = 2.7, 95% CI: 1.2,6.1)	Cooper, 1994
	Stair climbing (men)	≥ 15 flights / work day	(OR = 2.5, 95% CI: 1.0,6.4)	Lau, 2000
	Stair climbing (women)	≥ 15 flights / work day	(OR = 5.1, 95% CI: 2.5,10.2)	Lau, 2000
	Stair/Ladder climbing	> 30 flights / work day	(OR = 1.5, 95% CI: 1.0,2.3)	Coggon, 2000
	Lifting items ≥ 22 lbs (men)	≥ 10 times / work week	(OR = 5.4, 95% CI: 2.4,12.4)	Lau, 2000
	Lifting items ≥ 22 lbs (women)	≥ 10 times / work week	(OR = 2.0, 95% CI: 1.2,3.1)	Lau, 2000
	Lifting items ≥ 55 lbs	> 10 times / work week	(OR = 1.7, 95% CI: 1.2,2.6)	Coggon, 2000
	Lifting items ≥ 110 lbs	> 10 times / work week	(OR = 1.4, 95% CI: 0.9,2.2)	Coggon, 2000
	Lifting/carrying (women)	≥ 25-50 lbs / item	(OR = 2.53, 95% CI: 0.82,7.85)	Felson, 1991
	Heavy lifting combined with kneeling, squatting, or stair climbing	> 55 lbs / item	(OR = 5.4, 95% CI: 1.4,21.0)	Cooper, 1994
	Lifting/carrying combined with kneeling, squatting, crouching or crawling (men)	≥ 25-50 lbs / item	(OR = 2.22, 95% CI: 1.38,3.58)	Felson, 1991
	Heavy lifting combined with kneeling or squatting	> 55 lbs / item	(OR = 3.0, 95% CI: 1.7,5.4)	Coggon, 2000
	Walking	> 2 miles / work day	(OR = 1.9, 95% CI: 1.4,2.8)	Coggon, 2000
Tool Usage	Vibration tools (men)	> 1 hr / work day	(OR = 2.8, 95% CI: 0.8,10.0)	Lau, 2000
	Vibration tools (women)	> 1 hr / work day	(OR = 3.7, 95% CI: 0.7,20.1)	Lau, 2000

Table 3 Personal knee risk variables associated knee osteoarthritis

Personal Risk Type	Personal Risk	Statistical Measure	Source
Injury History	Past injury or surgery (men)	(OR = 12.1, 95% CI: 3.4,42.5)	Lau, 2000
	Past injury or surgery (women)	(OR = 7.6, 95% CI: 3.8,15.2)	Lau, 2000
Body Mass Index (Overweight)	BMI > 25.3	(OR = 3.6, 95% CI: 1.7,7.5)	Cooper, 1994
	BMI 25 – 29.9 (men)	(OR = 1.69, 95% CI: 1.03,2.80)	Anderson, 1988
	BMI 25 – 29.9 (women)	(OR = 1.89, 95% CI: 1.24,2.87)	Anderson, 1988
Body Mass Index (Obese)	BMI 30 - 35 (men)	(OR = 4.78, 95% CI: 2.77,8.27)	Anderson, 1988
	BMI 30 - 35 (women)	(OR = 3.87, 95% CI: 2.63,5.68)	Anderson, 1988
Body Mass Index (Very Obese)	BMI > 35 (men)	(OR = 4.45, 95% CI: 1.77,11.18)	Anderson, 1988
	BMI > 35 (women)	(OR = 7.37, 95% CI: 5.15,10.53)	Anderson, 1988

Table 4 Knee osteoarthritis related combinational risk of age, past injury/surgery and BMI with kneeling, squatting, or stair climbing postural activities

Personal Risk Type	Personal Risk	Statistical Measure	Source
Age	Age 45-54 (women)	(OR = 2.07, 95% CI: 0.71,6.08)	Anderson, 1988
	Age ≥ 55-64 (men)	(OR = 2.45, 95% CI: 1.21,4.97)	Anderson, 1988
	Age ≥ 55-64 (women)	(OR = 3.49, 95% CI: 1.22,10.52)	Anderson, 1988
Injury History	Past Injury or surgery	(OR = 7.6, 95% CI: 2.1,26.9)	Cooper, 1994
Body Mass Index (Normal weight)	BMI < 25	(OR = 2.2, 95% CI: 1.1,4.5)	Coggon, 2000
Body Mass Index (Overweight)	BMI 25 – 29.9	(OR = 6.1, 95% CI: 3.4,10.9)	Coggon, 2000
Body Mass Index (Obese)	BMI ≥ 30	(OR = 14.7, 95% CI: 7.2,30.2)	Coggon, 2000

Table 5 Occupational knee risk variables and knee meniscal disorders

Occupational Risk Type	Posture or Activity	Exposure Quantity	Statistical Measure	Source
Posture	Squatting	> 1 hr / work day	(OR = 1.8, 95% CI: 1.1,3.0)	Baker, 2002
	Squatting (men)	> 1 hr / work day	(OR = 2.5, 95% CI: 1.2,4.9)	Baker, 2003
	Kneeling	> 1 hr / work day	(OR = 2.2, 95% CI: 1.3,3.6)	Baker, 2002
	Kneeling (men)	> 1 hr / work day	(OR = 2.5, 95% CI: 1.3,4.8)	Baker, 2003
	Chair sitting (while driving)	> 4 hrs / work day	(OR = 2.3, 95% CI: 1.4,4.0)	Baker, 2002
Activity	Standing up from kneel or squat position	> 30 times / work day	(OR = 1.9, 95% CI: 1.2,3.1)	Baker, 2002
	Standing up from kneel or squat position (men)	> 30 times / work day	(OR = 1.9, 95% CI: 1.0,3.8)	Baker, 2003
	Stair climbing	> 30 flights / work day	(OR = 2.4, 95% CI: 1.6,3.8)	Baker, 2002
	Stair climbing (men)	> 30 flights / work day	(OR = 2.0, 95% CI: 1.0,4.1)	Baker, 2003
	Standing (men)	> 2 hrs / work day	(OR = 1.5, 95% CI: 0.8,3.1)	Baker, 2003
	Walking	> 2 miles / work day	(OR = 1.5, 95% CI: 0.9,2.3)	Baker, 2002
	Walking (men)	> 2 hrs / work day	(OR = 1.5, 95% CI: 0.8,3.1)	Baker, 2003
	Lifting or moving heavy items (men)	> 22 lbs / item	(OR = 1.7, 95% CI: 0.9,3.1)	Baker, 2003
	Lifting items ≥ 22 lbs	> 10 times / work week	(OR = 1.9, 95% CI: 1.2,2.9)	Baker, 2002
	Lifting items ≥ 55 lbs	> 10 times / work week	(OR = 1.7, 95% CI: 1.1,2.7)	Baker, 2002
	Lifting items ≥ 110 lbs	> 10 times / work week	(OR = 2.4, 95% CI: 1.4,4.2)	Baker, 2002

Table 6 Dose-Effect source study details

Dose-Effect Source	Disorder Type	Nature of Study	Participant Ages	Sample Size	Case Definition
Anderson, 1988	Knee OA	Retrospective	35-74	2428 male; 2765 female	NA
Baker, 2002	Meniscal Disorder	Prospective	20-59	196 male cases; 47 female cases; 461 controls	Knee meniscectomy
Baker, 2003	Meniscal Disorder	Retrospective	20-59	67 male cases; 335 male controls	Knee meniscectomy
Coggon, 2000	Knee OA	Retrospective	47-93	205 male cases; 205 controls; 313 female cases; 313 female controls	Confirmed Knee OA patients
Cooper, 1994	Knee OA	Retrospective	55-90	30 male cases; 60 male controls; 79 female cases; 158 female controls	Confirmed Knee OA
Felson, 1991	Knee OA	Retrospective	NA	569 male; 807 female;	Allowed knee radiographs; Provided occupational status information
Lau, 2000	Knee OA	Retrospective	NA	166 male cases; 166 male controls; 492 female cases; 492 female controls;	Confirmed Knee OA
Manninen, 2002	Knee OA	Retrospective	55-75	55 male cases; 140 male controls; 226 female cases; 384 female controls;	Knee arthroplastic surgery

Appendix B – Excerpt from Dissertation Literature Review

<u>Occupational Knee Disorders</u>

Knee disorders are the most common joint disorder for the LE. In their study of knee disorders affecting Britain's Hampshire communities, Baker et al. (2003) noticed that 14% of the population surveyed had a median number of lost days from work of 14. Additionally, they also mention that 1% of those surveyed had to leave their job due to their knee problem. From the literature, it is revealed that the majority of the knee disorders that result from kneeling inclined occupations are knee osteoarthritis, meniscal (meniscus) disorders, and knee bursitis (Baker, Reading, Cooper, & Coggon, 2003; Kivimaki, Riihimaki, & Hanninen, 1994). Appendix A's Table 1 refers to the risk variables involved with these listed knee disorders as well as association to discomfort. Table 6 in Appendix A above lists further detail on the dose-effect references being considered in the risk guidelines of Tables 1-5.

Knee Osteoarthritis

Osteoarthritis (OA) is a form of arthritis (joint inflammation) that involves the degenerative dissolution of normal cartilage behavior and function. Directly, OA cause cartilage to loose flexibility and become more firm. This loss in elasticity is a predisposition to destruction of the cartilage itself by allowing it to become damaged more easily during articulation and weight bearing activity. Breakdown of a joint's cartilage can not only cause a loss in shock absorption during weight bearing, but it can also allow ligament and tendon elongation and possibly bone to bone contact during joint movement, with the latter causing severe pain. Symptoms of OA in general, are joint inflammation and pain, as well as soreness during prolonged periods of usage or inactivity (WebMD). Confirmation of knee OA can be diagnosed using x-rays or an MRI. During the diagnosis process, a search is done for signs of worn cartilage, narrowed joint spaces, osteophytes, meniscus damage, and/or bony sclerosis and cysts (Felson, 2006). Knee OA severity is defined by grade levels 0 – 4. A grade of 0 means that there are no noticeable signs of degeneration. Grade 1 represents partial change in the joint with osteophytic lipping. Grade 2 denotes definitive osteophytes with a potential for joint space narrowing. Grade 3 shows numerous signs of osteophytes with an obvious decrease in joint space along with sclerosis and irregularity in bone and cartilage endings. The highest severity level of 4 shows an evident narrowing of joint spacing along with extreme bone end damage and sclerosis (Kellgren & Lawrence, 1963).

A multitude of occupations have been affected by knee OA. The listing of occupations includes miners, firemen, construction workers, taxi drivers, beverage delivery workers and many more (Table 7). The high quantity of jobs that are affected may be due to the commonness of the postural activities that are utilized by them. Postures noted by literature frequently refer to knee flexion and bending postures and activities such as kneeling (Coggon et al., 2000; Cooper, McAlindon, Coggon, Egger, & Dieppe, 1994; Jensen, Mikkelsen, Loft, & Eenberg, 2000; Kivimaki, Riihimaki, & Hanninen, 1992), squatting (Coggon et al., 2000; Cooper et al., 1994; Jensen, Mikkelsen, Loft, & Eenberg, 2000), and stair climbing (Lau et al., 2000). Additionally, Lau et al. (2000) mentions that vibration exposure from tools can also be considered as an occupational risk. Coggon et al. mention that in their study the activity of walking was also noted to correlate to knee OA (OR = 1.9, 95% CI: 1.4,2.8) (Coggon et al., 2000).

Table 7 Occupations affected by knee osteoarthritis

Occupation	Source
Firefighter	(Vingard, Alfredsson, Goldie, & Hogstedt, 1991)
Farm Worker	(Sandmark et al., 2000; Vingard et al., 1991)
Construction Worker	(Sandmark et al., 2000; Vingard et al., 1991)
Fishing Workers	(Lau et al., 2000)
Civil Servants	(Partridge, R. E. H. & Duthie, J. J. R., 1968)
Dock Worker	(Partridge, R. E. H. & Duthie, J. J. R., 1968)
Carpet/Floor Layer	(Jensen et al., 2000; Jensen, Mikkelsen, Loft, & Eenberg, 2000; Kivimaki et al., 1994)
Tilesetter	(Thun et al., 1987)
Forestry Worker	(Sandmark et al., 2000)
Carpenter	(Jensen et al., 2000; Jensen, Mikkelsen, Loft, & Eenberg, 2000)
Cleaning Workers (female)	(Rossignol et al., 2005; Vingard et al., 1991)
Miner	(Atkins, 1957; McMillan & Nichols, 2005)
Millwrights & Bricklayers	(Thun et al., 1987)

Several authors have noticed an association between physical workload (such as lifting and carrying) and knee OA (Coggon et al., 2000; Felson et al., 1991; Lau et al., 2000; Manninen, Heliovaara, Riihimaki, & Suomalainen, 2002; Sandmark, Hogstedt, & Vingard, 2000). Physical workload has been defined in several quantities but a standard of 5 levels have been used by the US government to denote exposure levels (US Department of Labor, 1977). The levels noted are sedentary, light, medium, heavy, and very heavy. Sedentary refers to handling only a maximum of 10 lbs with little walking or standing. Light physical workload has a maximum handling of 20 lbs with recurrent carrying of up to 10 lbs. Medium has a maximum of 50 lbs with 25 lbs of frequent carrying. Heavy physical workload has a 100 lb maximum with 50 lbs of recurring carrying. The last category of very heavy has a maximum lift that exceeds 100 lbs and frequent carries of greater than 50 lbs. Interestingly enough, studies have noticed that a combinational affect occurs when a physical workload is performed during knee bending postures and activities (Coggon et al., 2000; Cooper et al., 1994; Felson et al., 1991; Lau et al., 2000; Manninen et al., 2002; Sandmark et al., 2000). A few of these have even quantified this combinational affect to an extent, mentioning mainly that lifting and carrying items that weigh 25 to 55 lbs whilst kneeling, squatting, stair/ladder climbing, crouching, or crawling, can amplify possible knee OA progression (Table 2 in Appendix A) (Coggon et al., 2000; Cooper et al., 1994; Felson et al., 1991).

Occupational risks do make up the majority of possible causes to knee OA but, there are also several personal risk factors that are related to an individual's life history (Table 3 in Appendix A). For example, it is well-known that past knee problems such as meniscal disorders or even surgeries such as menisectomies can increase the likelihood that OA may develop later on in life (Cooper et al., 1994; Felson et al., 1991; Lau et al., 2000; Manninen et al., 2002; McMillan & Nichols, 2005; Wickstrom et al., 1983). Lau et al. (2000) reveal this correspondence to exist in both male and female genders (male: OR = 12.1, 95% CI: 3.4,42.5; female: OR = 7.6, 95% CI: 3.8,15.2). Cooper et al. (1994) view the combinational risk of past injury with kneeling, squatting, or stair climbing as a greater risk for this degenerative disorder (OR = 7.6, 95% CI: 2.1,26.9).

Obesity is another variable mentioned to be a factor in the development of knee OA (Anderson & Felson, 1988; Coggon et al., 2000; Cooper et al., 1994; Felson et al., 1991; Lau et al., 2000). Body mass index (BMI) is one indicator used to measure human body weight and its association with obesity. A BMI score of less than 20 is known as underweight; a score of 20-25 is considered as normal weight; a score between 25 and less than 30 is overweight; obese is considered a BMI greater than 30 and less than or equal to 35; and very obese is that greater than 35 (Anderson & Felson, 1988). Cooper et al. (1994) note that the threshold of risk begins with a BMI score of 25.3 (OR = 3.6, 95% CI: 1.7,7.5). Anderson and Felson (1988) point out that BMI scores indicating obese or greater are at risk for development of knee OA (male: OR = 4.78, 95% CI: 2.77,8.27; female: OR = 3.87, 95% CI: 2.63,5.68). Moreover, is the increased risk mentioned by Coggon et al. (2000) when high BMI is merged with kneeling and squatting postures (Table 4 in Appendix A). Overweight workers are already considered by their study to be at risk (OR = 6.1, 95% CI: 3.4,10.9), whereas obesity and above increases the connection (OR = 14.7, 95% CI: 7.2,30.2).

Lastly, some studies add that an aging workforce may also be a contributing personal factor in industry (Anderson & Felson, 1988; Felson et al., 1991). Although Anderson and Felson (1988) noticed that women in the age group of 45-54 were initially susceptible (OR = 2.07, 95% CI: 0.71,6.08), the authors particularly talk about those workers noted to be in the age group of 55-64 years old and higher having a greater inclination towards knee OA development for both gender groups when combined with knee bending postural activities such as kneeling, squatting, or stair climbing (male: OR = 2.45, 95% CI: 1.21,4.97; female: OR = 3.49, 95% CI: 1.22,10.52).

Personally attributable confounders such as habits and hobbies are also known to exist for knee OA risks. Lau et al. (2000) state that in their study they found athletic hobbies such as gymnastics and kung fu to be correlated to knee OA in Hong Kong Chinese women. High load bearing and repetition were seen as by the authors as the culprits of blame for these association. These same hobbies were not found to significant in men however.

Meniscal Disorders

A cumulative meniscal lesion or tear can occur when a portion of either the medial or lateral meniscus' cartilage is consistently caught in between the condyles of the femur and tibia during knee flexion which may slowly erode the material over time (Sharrard, W. J. W. & Liddell, F. D. K., 1962). Sharrard and Liddell (1962) propose another theory of meniscal damage by revealing that a predisposing cumulative laxity of the knee from kneeling may be a determinant that could lead to a sudden acute menisci tear. The area primarily accused is that of the anterior cruciate ligament (ACL) where it is noted that sudden jerking movements or extreme internal/external leg rotations (twisting) can lead to it stretching (or slowly tearing) over time while in a kneeling posture (Atkins, 1957; Sharrard, W. J. W. & Liddell, F. D. K., 1962). Sharrard and Liddell (1962) and Sharrard

(1964) disclose that the actual resulting evidence of meniscal damage may or may not occur while kneeling and can possibly happen while also walking, standing, stooping, or crawling. They infer that this may happen due to the knee's newfound laxity and instability. Sharrard (1964) adds that this sudden damage is due to a rapid movement (instead of static postures) such as a stagger or avoidance of a hazard in combination with the laxity that may cause abrupt meniscus lesions. Symptoms of the onset of meniscal disorders are perceived as pain, stiffness, knee locking, swelling, laxity, and grating, with the first two symptoms being the most commonly stated (Baker et al., 2003)

Meniscal lesions or tears are injuries commonly reported in athletic events such as soccer or rugby (Atkins, 1957; Baker et al., 2002; Baker et al., 2003). Additional risk association was found by Baker et al (2002, 2003) in running and swimming activities. Details of these athletic risk relationships are given in Baker's et al. (2003) study and are noted to be seen as possible confounders in men that participate in these activities (soccer: OR = 6.9, 95% CI: 3.5,13.3; rugby: OR = 3.4, 95% CI: 1.5,7.8; running: OR = 1.4, 95% CI: 0.5,3.7; swimming: OR = 1.6, 95% CI: 0.8,3.0).

There are considerably few studies that review the nature of occurrence of meniscal disorders, and of these, the occupations mentioned seem to continuously reference the mining and floor (or carpet) laying industries (Atkins, 1957; Jensen & Eenberg, 1996; Kivimaki, 1992; McMillan & Nichols, 2005; Sharrard, W. J. W. & Liddell, F. D. K., 1962) as the common occupations studied. It can be safe to assume though that other industries can also be susceptible where knee bending postures and activities are heavily utilized. Of the studies reviewed for this disorder, only two (Baker et al., 2002, 2003) provided statistical measures for occupational risk factors. Risk factors that are mentioned are kneeling, squatting, stair climbing, standing, sitting while driving, walking, and lifting and carrying heavy objects (Table 5 in Appendix A). Moreover, both studies also add that the act of getting up from a kneeling or squatting position can add strain to the knee that could possibly lead to meniscal damage. Baker et al. (2003) propose a risk association when this act is performed more than 30 times per work day (OR = 1.9, 95% CI: 1.0, 3.8). Personal risk factors were unable to be found for this review from the studies located.

Knee Bursitis

Bursitis is the irritation and inflammation of a bursa sac and can be diagnosed as either acute or chronic. For the knee joint, the two most commonly affected bursas are the prepatellar bursa (along the anterior portion of the patella bone) followed by the superficial infrapatellar bursa (along the anterior-superior portion of the tibia bone of the knee joint) (Myllymaki, Tikkakoski, Typpo, Kivimaki, & Suramo, 1993). Pseudonyms of knee bursitis are known as "beat knee" from the coal mining industry (Myllymaki et al., 1993; Sharrard, W. J. W., 1964; Thun et al., 1987; Watkins, Hunt, Fernandez, R. H. P., & Edmonds, 1958), "carpet-layer's knee" from carpet and floor laying (Myllymaki et al., 1993; Thun et al., 1987) and "housemaid's knee" (Thun et al., 1987). Myllymaki et al. (1993) describe symptoms of knee bursitis to include redness and tenderness, and swelling of the affected knee bursa area in the prepatellar region. Detection tools of bursitis in general, include radiographs, magnetic resonance images (MRI), and ultrasounds, with the latter being more accurate than radiographs and faster and less costly than MRIs. Diagnosis of bursitis by ultrasound includes detection of oval-like hypoechoic structures accompanied by fluid aggregation and possible bursa thickening.

Knee bursitis has been noted in the literature to occur in a multitude of occupations. Typically, the disorder is associated to jobs that entail protracted knee straining work such as kneeling and squatting (Jensen, Mikkelsen, Loft, & Eenberg, 2000). Occupations notorious for extended kneeling postures are coal mining (Myllymaki et al., 1993; Sharrard, W. J. W., 1964; Thun et al., 1987; Watkins et al., 1958) and carpet (floor) laying (Bhattacharya, Mueller, & Putz-Anderson, 1985; Jensen, Mikkelsen, Loft, & Eenberg, 2000; Kivimaki, 1992; Myllymaki et al., 1993; Thun et al., 1987). Kivimaki et al. (1992) noticed in their study that 19% of their carpet layers developed prepatellar bursitis. In Jensen's et al (2000) study, the two investigating physicians diagnosed 10% and 8% of the carpet laying workers with knee bursitis. 20% of Thun's et al. (1987) carpet laying participants were diagnosed with knee bursitis during the study. In Watkins' et al. (1958) study of beat knee in coal mining, the average lost work shifts was 5.7 and 10% of the 899 participants had recurring episodes of knee bursitis. Additional occupations aside from the mining and floor laying industries include house cleaning (Myllymaki et al., 1993; Thun et al., 1987) tile setting (Thun et al., 1987), and manufacturing (Bruchal, 1995), as well as the sport of wrestling (Myllymaki et al., 1993). Fishermen at sea also are known to develop prepatellar bursitis due to the pressure exerted on the prepatellar knee region by the boat's equipment and surfaces (Torner, Almstrom, Karlsson, & Kadefors, 1994). The authors mention that the knee disorder actually develops during standing while the workers are performing their tasks and need to stabilize themselves with the front of their legs and knees during the boat's rocking movements.

As previously stated, kneeling is the primary occupational risk variable associated with the development of prepatellar and superficial infrapatellar bursitis. Thun's et al. (1987) study showed that when compared to tile setters, millwrights, bricklayers, and carpet layers were revealed to have a higher prevalence towards developing knee bursitis (Prevalence Ratio = 3.2). The authors propose that this is likely due to the high repetition and duration of kneeling within their occupation. Sharrard's (1964) review of coal mining implies that due to the dynamically fluctuating pressures that the prepatellar regions of the knees are exposed to while kneeling and working, it is of no surprise that blood vessels would eventually rupture in the prepatellar bursa and produce the swelling and haemobursa noticed in acute prepatellar bursitis. Few knee pads of the day did provide reasonable protection to the prepatellar bursa against this alternating knee pressure. Although 91% of Watkins' et al. (1958) surveyed participants did wear knee pads daily while working, prepatellar bursitis still occurred. A concurrence with this premise is mentioned by Sharrard (1964) who reveals that prepatellar bursitis occurred twice as frequently as did its superficial infrapatellar counterpart. Watkins et al. (1958) point out that even though the knee's contact area with the work surface (while kneeling) focuses on the tibial tuberosity (below the patella), they feel that knee pads themselves may be redistributing the body weight's pressure back onto the prepatellar region. Some of the studies also noticed a connection between restricted work environments and recurrent usage of kneeling related postures due to this confinement (Sharrard, W. J. W., 1964; Watkins et al., 1958).

Use of a knee kicker is another occupational hazard that solely transpires in the carpet laying industry. The device is used to stretch carpet snuggly to a wall during installation (Thun et al., 1987). During this activity, while in a crawl position one of the knees is used as a hammer against the tool while the other holds a portion of the body's weight (some is transferred into the arms as well). Thun et al. (1987) reveals that it is the suprapatellar region of the knee that provides the contact stress against the tool. An assessment done by Bhattacharya et al. (1985) discovered that the least forceful knee kicks against the tool provided 2469 N of force whereas a more excessive one could hit as high as 3019 N (approximately four times participant's body weight). An association was found by Thun et al. (1987) between use of a knee kicker and the development of knee bursitis (OR = 5.3, 90% CI: 2.8, 10.3).

Appendix C – Risk Model Matrix Example

Subject # 5	**Task Duration** (# of hours)	**Stair Climbing** (# of stories)	**Lifting >55 lbs per item** (# of times)	**Squatting** (# of hours)	**Total Risk Scores**
Task 1	2	7	3	0.5	((7/18)(5)) + ((3/9)(4)) + ((0.5/4)(7)) = **4.1528**
Task 2	4	1	6	3	((1/18)(5)) + ((6/9)(4)) + ((3/4)(7)) = **8.1944**
Task 3	2	10	0	0.5	((10/18)(5)) + ((0/9)(4)) + ((0.5/4)(7)) = **3.6528**
Totals	8 hours	18 stories	9 times	4 hours	**NA**
Risk Variable Score (product of variable weight and multiplier)	**NA**	5	4	7	5+4+7 = **16** (Total Subject Daily Risk)

Occupational Lower Extremity Risk Assessment Modeling - The Knee – Hazard Analysis

This Task Hazard Analysis section of the study will allow researchers to compare professional judgment of a task's hazardous level to the results of the Lower Extremity Risk Assessment (LERA) tool score for the knee region. Please review the individual's working in this task and assess the overall risk to the knee(s). This evaluation should take you no more than 10 minutes to complete the questions below:

1. In your professional opinion, is there a positive or negative association of this task to possible knee morbidity?

   Yes☐ No☐

2. Based on the first question, if your answer was positive, then would one knee or both knees be affected?

   One knee☐ Both knees☐

3. If the answer to question #2 was one knee, then which knee would most likely be more affected (left/right)?

   Left knee☐ Right knee☐

Reviewer #: _______________

Date of analysis: _________________________

Task name being reviewed: ____

Study Task #: _______________

Task plane program: _______________________

Task IP and or Control Code (CC): ____

Task Bldg./Floor/Column:_______________________________________

Or

Task Aircraft Floor/Location: _______________________________________

Occupational Knee Risk Assessment Modeling - The Knee – Task Observation

Live Observation Stage

Reviewer #: _______________

Date of analysis: ________________________

Task name being reviewed: ____

Study Task #: _______________

Task plane program: ______________________

Task IP and or Control Code (CC): ____

Task Bldg./Floor/Column:_____________________________________
Or
Task Aircraft Floor/Location: _____________________________________

The following personal risk-related questions will be asked to each employee participating in the Task Observation stage of the research study.

1. Task participant #: ___________
2. Age: _____________
3. Gender: Male or Female
4. BMI – Please choose from the BMI chart your approximate BMI Score according to you height and closest body weight. This chart was developed based on information obtained from the Center for Disease Control BMI formulas (http://www.cdc.gov/nccdphp/dnpa/bmi/adult_BMI/about_adult_BMI.htm)

   BMI Score: _________

5. Have you had any past (physician diagnosed) knee disorders or knee surgeries?

   Yes☐ No☐

   If Yes, please list the injuries or surgeries and the knee(s) affected below:

   ____

   ____

   ____

   ____

6. Any knee risk-related habits/hobbies/sports performed routinely (weekly/monthly) outside of work?

   Yes☐ No☐

   If Yes, please list them below:

   ____

   ____

   ____

   ____

7. Any presently residing knee pain that causes behavioral activity changes during or outside of work?
   Yes☐ No☐

   If Yes, please list the knee(s) affected below:

   ____

   ____

   ____

   ____

Adult Body Mass Index (BMI) Score Chart

BMI Score		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Height (ft)	(in)	Body Weight (lbs)														
	55	82	86	90	95	99	103	108	112	116	120	125	129	133	138	142
	56	85	89	94	98	103	107	112	116	120	125	129	134	138	143	147
	57	88	92	97	102	106	111	116	120	125	129	134	139	143	148	153
	58	91	96	100	105	110	115	120	124	129	134	139	144	148	153	158
	59	94	99	104	109	114	119	124	129	134	139	144	149	154	158	163
5 ft	60	97	102	108	113	118	123	128	133	138	143	149	154	159	164	169
	61	101	106	111	116	122	127	132	138	143	148	153	159	164	169	175
	62	104	109	115	120	126	131	137	142	148	153	159	164	170	175	180
	63	107	113	119	124	130	135	141	147	152	158	164	169	175	181	186
	64	111	117	122	128	134	140	146	151	157	163	169	175	181	186	192
	65	114	120	126	132	138	144	150	156	162	168	174	180	186	192	198
	66	118	124	130	136	143	149	155	161	167	173	180	186	192	198	204
	67	121	128	134	140	147	153	160	166	172	179	185	192	198	204	211
	68	125	132	138	145	151	158	164	171	178	184	191	197	204	210	217
	69	129	135	142	149	156	163	169	176	183	190	196	203	210	217	223
	70	132	139	146	153	160	167	174	181	188	195	202	209	216	223	230
	71	136	143	151	158	165	172	179	186	194	201	208	215	222	229	237
6ft	72	140	147	155	162	170	177	184	192	199	206	214	221	229	236	243
	73	144	152	159	167	174	182	190	197	205	212	220	227	235	243	250
	74	148	156	164	171	179	187	195	203	210	218	226	234	241	249	257
	75	152	160	168	176	184	192	200	208	216	224	232	240	248	256	264
	76	156	164	173	181	189	197	205	214	222	230	238	246	255	263	271
	77	160	169	177	186	194	202	211	219	228	236	245	253	261	270	278
	78	164	173	182	190	199	208	216	225	234	242	251	260	268	277	286

* First choose height on left side and then move along to the right to your closest approximate weight. The corresponding BMI Score will be above this weight of the same column. This chart is based on formulae from the Center of Disease Control (CDC).

BMI Score Chart (continued)

BMI Score		34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Height (ft)	(in)	Body Weight (lbs)																
	55	146	151	155	159	164	168	172	176	181	185	189	194	198	202	207	211	215
	56	152	156	161	165	170	174	178	183	187	192	196	201	205	210	214	219	223
	57	157	162	166	171	176	180	185	189	194	199	203	208	213	217	222	226	231
	58	163	167	172	177	182	187	191	196	201	206	211	215	220	225	230	234	239
	59	168	173	178	183	188	193	198	203	208	213	218	223	228	233	238	243	248
5 ft	60	174	179	184	189	195	200	205	210	215	220	225	230	236	241	246	251	256
	61	180	185	191	196	201	206	212	217	222	228	233	238	243	249	254	259	265
	62	186	191	197	202	208	213	219	224	230	235	241	246	252	257	262	268	273
	63	192	198	203	209	215	220	226	231	237	243	248	254	260	265	271	277	282
	64	198	204	210	216	221	227	233	239	245	251	256	262	268	274	280	285	291
	65	204	210	216	222	228	234	240	246	252	258	264	270	276	282	288	294	300
	66	211	217	223	229	235	242	248	254	260	266	273	279	285	291	297	304	310
	67	217	223	230	236	243	249	255	262	268	275	281	287	294	300	307	313	319
	68	224	230	237	243	250	257	263	270	276	283	289	296	303	309	316	322	329
	69	230	237	244	251	257	264	271	278	284	291	298	305	312	318	325	332	339
	70	237	244	251	258	265	272	279	286	293	300	307	314	321	328	335	342	349
	71	244	251	258	265	272	280	287	294	301	308	316	323	330	337	344	351	359
6ft	72	251	258	265	273	280	288	295	302	310	317	324	332	339	347	354	361	369
	73	258	265	273	280	288	296	303	311	318	326	334	341	349	356	364	371	379
	74	265	273	280	288	296	304	312	319	327	335	343	351	358	366	374	382	389
	75	272	280	288	296	304	312	320	328	336	344	352	360	368	376	384	392	400
	76	279	288	296	304	312	320	329	337	345	353	362	370	378	386	394	403	411
	77	287	295	304	312	320	329	337	346	354	363	371	380	388	396	405	413	422
	78	294	303	312	320	329	338	346	355	363	372	381	389	398	407	415	424	433

* First choose height on left side and then move along to the right to your closest approximate weight. The corresponding BMI Score will be above this weight of the same column. This chart is based on formulae from the Center of Disease Control (CDC).

APPENDIX D: SPSS GENERATED STATISTICAL RESULTS

Mann-Whitney U Test for the Model's Initial Iteration

NPar Tests

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Risk Scores	17	2.8676	1.03877	1.50	5.50
Task Grouping	17	.4118	.50730	.00	1.00

Descriptive Statistics

	Percentiles		
	25th	50th (Median)	75th
Risk Scores	2.5000	2.7500	3.0000
Task Grouping	.0000	.0000	1.0000

Mann-Whitney Test

Ranks

	Task Grouping	N	Mean Rank	Sum of Ranks
Risk Scores	Safe Group	10	6.00	60.00
	Hazardous Group	7	13.29	93.00
	Total	17		

Test Statistics[b]

	Risk Scores
Mann-Whitney U	5.000
Wilcoxon W	60.000
Z	-3.010
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.002[a]

a. Not corrected for ties.

b. Grouping Variable: Task Grouping

Mann-Whitney U Test for the Model's Second Iteration

NPar Tests

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Risk Scores	17	1.5588	1.08804	.00	4.50
Task Grouping	17	.4118	.50730	.00	1.00

Descriptive Statistics

	Percentiles		
	25th	50th (Median)	75th
Risk Scores	1.0000	1.5000	1.5000
Task Grouping	.0000	.0000	1.0000

Mann-Whitney Test

Ranks

	Task Grouping	N	Mean Rank	Sum of Ranks
Risk Scores	Safe Group	10	6.80	68.00
	Hazardous Group	7	12.14	85.00
	Total	17		

Test Statistics[b]

	Risk Scores
Mann-Whitney U	13.000
Wilcoxon W	68.000
Z	-2.286
Asymp. Sig. (2-tailed)	.022
Exact Sig. [2*(1-tailed Sig.)]	.033[a]

a. Not corrected for ties.

b. Grouping Variable: Task Grouping

One Sample t Test for the Model's Second Iteration Risk Level

T-Test

Group Statistics

	Method Source	N	Mean	Std. Deviation	Std. Error Mean
Task Grouping	Subject Matter Expert Consensus	17	1.4118	.50730	.12304
	Model Resultant Score	17	1.1765	.39295	.09531

Independent Samples Test

		Levene's Test for Equality of Variances	
		F	Sig.
Task Grouping	Equal variances assumed	8.784	.006
	Equal variances not assumed		

Independent Samples Test

		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
Task Grouping	Equal variances assumed	1.512	32	.140	.23529
	Equal variances not assumed	1.512	30.118	.141	.23529

Independent Samples Test

		t-test for Equality of Means		
			95% Confidence Interval of the Difference	
		Std. Error Difference	Lower	Upper
Task Grouping	Equal variances assumed	.15563	-.08172	.55231
	Equal variances not assumed	.15563	-.08250	.55309

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