ARE THE THRESHOLD LIMIT VALUES (TLVS®) FOR LIFTING PROPOSED BY THE AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS INDEPENDENT OF GENDER AND ANTHROPOMETRY?

A Thesis by

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Industrial Engineering.

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Michael Jorgensen, Committee Chair

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Mehmet Bayram Yildirim, Committee Member

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Ramazan Asmatulu, Committee Member

DEDICATION

To my parents, my sister, and my lovely daughter

Making the difference begins when you start doing what you have been thinking

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ABSTRACT

Low back disorders remains the top musculoskeletal disorder across several industries, where lifting is commonly associated as a major risk factor in the workplace. Researchers have developed numerous assessment methods to identify high-risk jobs, where the ACGIH Lifting Threshold Limit Values (TLV) assessment method one of the most recent methods, providing guidelines to protect virtually any individual with a certain duration, frequency, and horizontal and vertical distance, protecting the individual from work-related shoulder and/or low back disorders associated with lifting.

Several research voids were found for the ACGIH Lifting TLV method regarding gender, anthropometry, acquire versus placing an object, horizontal distance, and when the origin and final destination differs. A controlled experiment utilizing the probability of the Low Back Disorder (LBD) Risk using the Industrial Lumbar Motion Monitor (iLMM) was conducted to assess these voids. The experimental task consisted of lifting a box with handles from randomly selected locations of two vertical and four horizontal distances, to a fixed destination adjusted to each individual‟s waist height. Eighteen anthropometry-gender mixed subjects acquired and placed the box four times from each zone, with a complete interval of fifteen seconds each time. Results showed that essentially there is no significant difference among either gender or anthropometry raging within low- to medium- LBD Risk probabilities. In conclusion, the ACGIH lifting TLVs table for frequent lifting tasks appears to be appropriate to be applied regardless gender or anthropometry in the workplace environment with similar lifting conditions as described in the method. Also may be used to assess both origin and destination of the lifting task.

TABLE OF CONTENTS

Chapter **Page**

TABLE OF CONTENTS (continued)

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

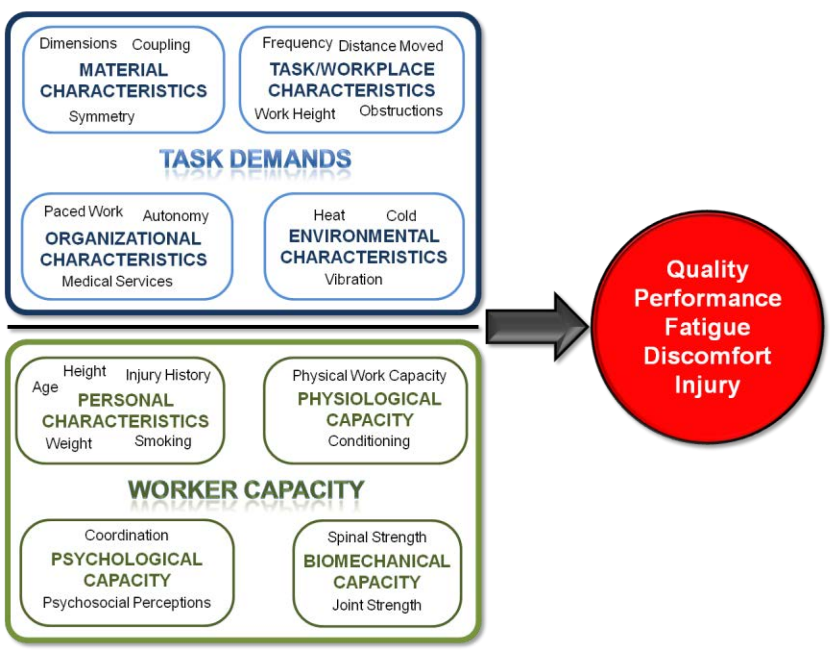
LIST OF ABBREVIATIOS

ACGIH	American Conference of Governmental Industrial Hygienists
Anthropom	Anthropometric
Avg. Vel.	Average Velocity
BLS	U.S. Bureau of Labor Statistics
Cm	Centimeters
Deg	Degrees
Ext	Extended
H	Horizontal
iLMM	Industrial Lumbar Motion Monitor
LBD	Low Back Disorder
Max. Acc.	Maxim Acceleration
Max. Pos.	Maximum Position
Max. Vel.	Maximum Velocity
Mid	Middle
Min. Pos.	Minimum Position
MMH	Manual Material Handling
MSD	Musculoskeletal disorder
NIOSH	National Institute for Occupational Safety and Health
Sec	Seconds
V	Vertical

CHAPTER 1

INTRODUCTION

While one of management‟s objective is to improve productivity and an ergonomist‟s is to reduce discomfort, health problems and fatigue, both share the same goal of making the job safer and more efficient. Since the 1950s, manual material handling (MMH) has been an object of study with the ultimate goal of ensuring that the operator‟s tasks will not to exceed their limits in its cardiopulmonary and musculoskeletal systems to avoid chronic injuries (Dempsey & Mathiassen, 2006). The MMH analysis breaks down the complex situation into individual tangible measurable tasks. Researchers have identified and classified factors into two groups, task demands and workers capacity (figure 1), that could lead into a negative outcome either for the operator or the product (Dempsey, 1998).



Note: (adapted Dempsey 1998)

Figure 1. Primary factors influencing the task demands to worker capacity ratio.

Pushing, pulling, holding, carrying, lowering and lifting tasks, commonly known as MMH activities, are present in many manufacturing and service industries in different magnitudes. Even though revolutionary technologies such as automation have reduced exposure in some MMH tasks, there are many other tasks that for now machines cannot replace, where some of these tasks are responsible for compensable injuries (Dempsey, 1998). Mäntyselkä et al. (2001) found that two out of every five Finns visited a physician because of pain, where musculoskeletal disorders accounted about half of the cases. Low back pain was the top reason for males between 20-59 years and the second reason for females of the same age range. Today, low-back disorders (LBD) still remains as the top musculoskeletal disorder among several industries (BLS, 2007).

The latest published data from the U.S. Bureau of Labor Statistics (2007) showed that there has been a decrease in injury claims in private industry but it is still a significant issue. Shown below is information extracted from the U.S. Bureau of Labor Statistics (2007) nonfatal occupational injuries and illnesses requiring days away from work report:

- **Sprains and strains** were the most frequent nature of injuries and illnesses with 448,380 cases.
- The **part of the body** most often **affected by work injuries** was the **trunk** (including the **shoulder** and **back**), accounting for 33 percent of all injuries and illnesses (see appendix 1).
- Injuries involving the shoulder took workers a median of 18 days to return to work for all private industries. Half of the injuries to the shoulder were the result of overexertion.

- Workers in goods-producing industries took a median of 26 days away from work and those in service-providing industries required 15 days. Injuries from **repetitive motion continue** to be the event with the **highest median days away from work** for all private industries (20 days) and service-providing industries (19 days).
- Workers who were 20 to 24 years of age had the highest overall incidence rate at 134 cases per 10,000 full-time workers per year. Workers 65 years old and older had the lowest overall incidence rate of 96 cases per 10,000 workers per year.
- Males accounted for 64 percent of injuries and illnesses and had an incidence rate of 134 cases per 10,000 workers per year, 22 percent higher than the rate for females (105 cases per 10,000 workers per year).
- **Laborers and freight, stock, and material movers** experienced the **highest number of days-away-from-work injuries and illnesses**, with 79,000 in 2007. Following this occupation were heavy and tractor trailer truck drivers (57,050), nursing aides, orderlies and attendants (44,930), construction laborers (34,180), and light or delivery service truck drivers (32,930).

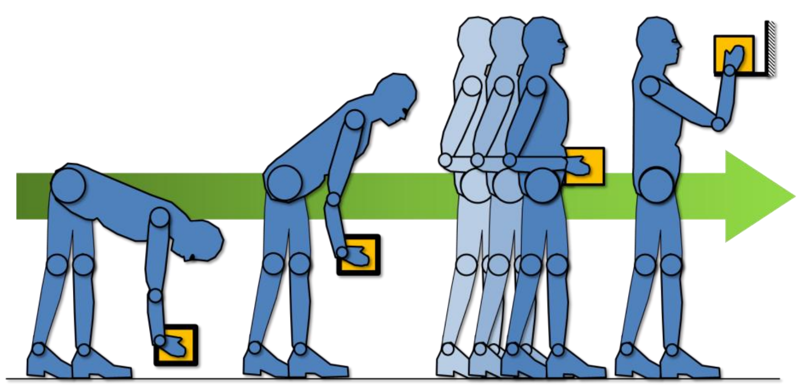


Figure 2. Worker lifting an object

There are different sources that could lead to LBD, but lifting is commonly associated as a major risk factor in the workplace (Snook et al., 1978). Researchers have developed numerous assessment methods to identify high-risk jobs, aim for solutions, and evaluate the effectiveness of potential solutions for lifting. Many assessment methods throughout time have been discarded for different reasons, oftentimes because new findings through research discovered new relevant factors that those tools didn‟t take into account, in addition to validity and accuracy issues (Marras et al., 1999; Russell et al., 2007). Currently five lifting tools are typically used by ergonomists:

- **Revised 1991 National Institute for Occupational Safety and Health (NIOSH)** Lifting Equation (Waters et al. 1993);
- **American Conference of Governmental Industrial Hygienists (ACGIH)** lifting Threshold Limit Values (ACGIH, 2009);
- **Liberty Mutual Lifting Tables**, Liberty Mutual Manual Material Handling Tables (Snook and Ciriello, 1991; Liberty Mutual, 2004);
- **University of Michigan 3D Static Strength Prediction Program (3DSSPP)** (University of Michigan, 2001);
- **Washington State Ergonomics Rule Lifting Calculator** (WAC, 2000a, b).

Each of these assessment methods has unique attributes that result in each one still being used. The NIOSH method is universally recognized and widely used. The ACGIH Lifting TLV tool is based somewhat on the NIOSH method but also designed to be more user friendly, and is one of the newest developed methods. The Liberty Mutual Lifting Tables are mainly utilized to obtain design guidelines. The 3DSSPP is a biomechanical modeling assessment tool for low back compression and shear forces. Finally, the Washington State Ergonomics Rule Lifting Calculator, also based somewhat on the NIOSH method, was used as a regulatory instrument in Washington State and was designed to assess and identify the highest risk jobs due to lifting. Table 1 summarizes the five assessment methods and the variables that each one takes into account to assess any given job.

Russell et al. (2007) analyzed the above mentioned assessment methods for lifting tasks and concluded that NIOSH, ACGIH, and the Liberty Mutual Lifting Tables were similar in identifying the risk when applied to a uniform task. Marras et al. (1999) found that high-risk jobs were correctly identified by NIOSH, and low to moderate risk jobs were more accurately identified by the Liberty Mutual Lifting Tables. Worth mentioning is that the NIOSH lifting equation offers greater interpretive capabilities to identify which input variables (e.g. angle of asymmetry, frequency of lift, and horizontal and vertical location of the object to be lifted) from a given task should be addressed to give the most benefit to reduce the risk of injury. However the NIOSH Lift Equation requires more time, and a certain level of expertise and knowledge of equations. ACGIH and Liberty Mutual use tables that are easier to apply and obtain more timely results as well. The ACGIH suggests threshold limit values and the Liberty Mutual estimates a percentage level of acceptable female/male population that could perform such work according to the working conditions.

TABLE 1

INPUT VARIABLES AND RESULTS OF FIVE LIFTING ASSESSMENT TOOLS

Input Variables	WA L&I	NIOSH	ACGIH Lifting TLV	Liberty Mutual	3DSSPP
Anthropometry Height	✓		✓	✓	✓
Joint Angles					✓
Maximum Lift (kg)	41	23	32	Subject based	
Frequency	✓	✓	✓	✓	
Duration	✓	✓	✓		
Lift origin (H&V)	✓	✓	✓	✓	✓
Destination (H&V)		✓			
Load Travel Distance	✓	✓		✓	
Coupling		✓			
Torso Asymmetry	✓	✓			✓
Outcome	Lifting Limit	Recommended weight limit; lifting index	Threshold limit value; maximum weight limit	Design goal; % strength capable	L5/S5 compression force; % strength capable, joint moments

Note: H&V = Horizontal & Vertical distances. Adapted from Russell et al., 2007

The main difference between the Liberty Mutual Tables and the ACGIH Lifting TLV tables is that the Liberty Mutual Tables has a different table for females than for males, with lower acceptable weight for females, whereas the ACGIH does not differentiate for gender. This raises the question that the ACGIH maybe overestimating the recommended TLVs for females, or underestimating the TLVs for males. Research such as Marras et al. (2002) found a significant difference, under controlled lifting conditions, in spine loadings as a function of gender due in part to different body masses. Moreover, Ford et al. (2000) studied world weightlifting champions with respect to gender and height related limits of muscle strengths, and concluded that height and body strengths are proportional. Additionally, they found that women are taller than men for lighter body-weight classes but for the heavier classes, men are taller, suggesting gender and height differences in performance.

Therefore, the ACGIH Lifting TLV method was selected to be analyzed from the other assessment methods due to its straight forward use, is fairly new, and hasn"t been analyzed extensively. Additionally, the ACGIH Lifting TLV tables require further research regarding gender, anthropometry, and/or location of the box to be lifted to ensure that these tables include these variables which are considered to be important. In order to achieve that, this research evaluated the lifting weight limits suggested by the ACGIH method and compare to a validated LBD Risk assessment index (Marras et al. 1993, 2000).

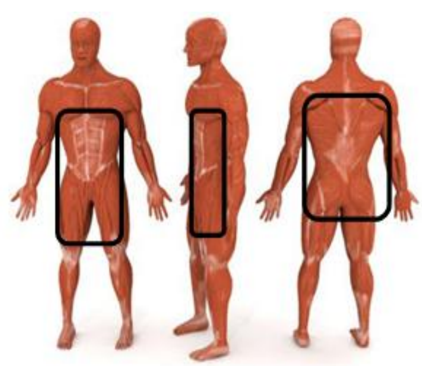
CHAPTER 2

LITERATURE REVIEW

2.1 Anatomy and Biomechanics of Manual Handling: Lifting

When an object is being lifted, the loading is transferred to the body in the form of compression and shear forces to the spinal column. According to Newton‟s law of motion, higher internal forces are required to accelerate the mass from rest when the load is lifted quickly. As more asymmetric (e.g. torso twisting) the posture, additional loads are placed on the spine (Granata & Marras, 2000).

An external extension moment exists about the lumbar spine when a person leans forwards to lift an object. The heavier and more distant the object is from the body, the greater the external extension moment. To counteract the external extension moment and to perform the lift, the posterior torso muscles contract to create an internal moment about the spine, which comes with an opposed contraction of the anterior abdominal muscles (Bridger, 2003), which further increases the loading on the spine. Figure 3 illustrate the main muscles area of the human body which are actively involved during lifting.



Source: http://www.turbosquid.com/3d-models/3d-muscular-male-muscles/426472

Figure 3. Main muscular area involved in lifting

2.2 Back Injuries and Lifting

According to Grieve and Pheasant (1982), the trunk can fail in three ways when a weight is lifted:

- Under excessive tension, the muscles and ligaments of the back can fail.
- Under excessive compression, the intervertebral disc may herniate as the nucleus is extruded.
- Excessive intra-abdominal pressure, the abdominal contents may be extruded through the abdominal cavity.

These injuries are commonly known as „muscle strains or tears", „hernias", and „prolapse discs".

2.3 Work Related Musculoskeletal Disorders

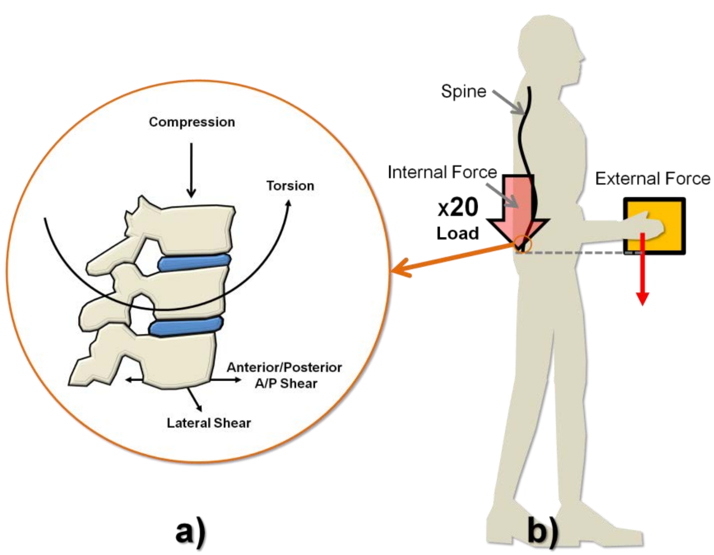
The Occupational Health and Safety Council of Ontario (OHSCO) defines musculoskeletal disorders as injuries and disorders of the musculoskeletal system as a result of or aggravated by a variety(ies) of hazards, except as a result of an accident, affecting muscles, nerves, tendons and tendon sheaths, blood vessels, joints/spinal discs, and ligaments.

2.3.1 Low Back and Shoulder Pain

Musculoskeletal disorders of the back and shoulder are mainly caused from manual material handling tasks due to muscular fatigue. Depending of the severity, it can become an acute pain resulting in the individual staying away from work (Bridger, 2003; Konz & Johnson, 2008).

2.3.2 Spinal Load when Lifting

Injury to the low back occurs when the spine tolerance is exceeded as a result of an interaction between dynamic spinal loads and tissue strains, which can be associated with the probability of high LBD risk (Granata & Marras, 1999). Many studies have shown that lifting task design (e.g. frequency and duration of the task, load weight, and location of the object to be lifted) is capable of damaging low back musculoskeletal tissues through biomechanical loads on the spine (ACGIH, 2001; Granata & Marras, 1999). When lifting, muscles, facet joints, ligaments, and intervertebral discs of the spine, support and resist compression, torsion, and shear forces (Figure 4). These elevated forces occur as a result of a mechanical disadvantage within the muscles from the back which during a lift, result in higher loading on the spinal tissues, where the compression forces can be more than twenty times greater than the external load (Figure 4) (Keyserling, 2000).



Note: Adapted from Keyserling, 2000

Figure 4. a) Three-dimensional loading on the spine; b) relationship between internal and external forces acting upon the spine

Marras et al. (1993), Water et al. (1993), and ACGIH (2001) addressed the following risk factors, each one by itself or combined, associated to reduce the tolerance limits of the tissues and to induce LBD and/or shoulder pain.

- Torso flexion;
- Frequency or lift rate;
- Duration of the lifting task;
- External load moment (i.e., weight and distance from the body);
- Torso asymmetry (i.e., twisting).

Each of these risk factors are discussed below.

2.3.3 Torso Flexion

Numerous epidemiological and research studies have identified torso flexion to be associated with the increase in risk of LBD (Kelsey et al, 1984; Snook et al, 1985; Punnett et al, 1991; Marras et al., 1993, 1995). During torso flexion, spinal stability is decreased as well as the extensor muscles ability to resist external loads (Van Dieen et. al, 1999). Also the amount of shear forces over the intervertebral discs increases (Fathallah et. al, 1998) and the intervertebral discs have lower tolerances to compressive forces (McGill, 1996), thus increasing the risk of a LBD.

An increase in the strain on the posterior fibers of the annulus fibrosus of the intervertebral discs occurs when repeated induced forward bending moments are performed close to the extreme flexion of the motion segment (Adams et al. 1994).

2.3.4 Frequency and Duration of the lifting task

Numerous epidemiological studies discovered that when a lifting task is performed at a repetitive pace, repetition could become a risk factor leading to LBD

(Parnianpour et al., 1988; Marras et al., 1995; Kraus et al., 1997). Brinckmann et al. (1988) suggested that load weight and load frequency are closely linked with fatigue fractures of the vertebral bodies.

2.3.5 External Load Moment

The external load moment results from the force transmitted at a certain distance from the musculoskeletal and osteoligamentous disc system, where most of the stress is induced to the low back (L5/S1 lumbosacral disc) (Marras et al., 1995). Numerous studies from Marras et al. (1993, 1995, and 2000) found that the best single predictor of being a high-risk LBD case was the maximum external load moment. The load moment and spinal loading are directly proportional, as the external load moment increases, spinal loading increases as well (Granata and Marras, 1995). Other research has found that high load moments (distance from the body), trunk asymmetry, and lifting frequencies were associated with high-risk jobs (ACGIH, 2001; Marras, 2006).

2.3.6 Torso Twisting

Kelsey et al. (1984) found an increased risk of acute prolapsed lumbar intervertebral disc when twisting of the torso was performed while lifting objects. Punnett et al. (1991) found that there was a higher risk of LBD when the duration of task combined with asymmetry increases. Twisting motion increases both torso muscle co-contraction (Marras et al. 1998) and spinal loading due to torso muscle coactivation (Granata and Marras, 1995). Moreover, muscle effort also increases gradually as twist increases (Toren, 2001).

2.3.7 Gender and Anthropometry

Several researchers have found that gender makes a difference when different body masses are applied performing the same tasks (Jäger et al., 1991; Macfarlane et al., 1997; Vinegård et al., 2000). Marras et al. (2002) performed an in vivo laboratory study assessing the spine loading as a function of gender, testing 140 subjects (70 females and 70 males) performing a controlled motion and free-dynamic whole body lifts. Results showed a significant difference in spine loading between genders as a function of the anatomic differences in torso muscle sizes, and differences in muscle co-contraction. Females demonstrated higher muscle co-contraction when lifting the same loads, and higher spinal loading. Furthermore, females have lower loading tolerance to the soft tissues such as the intervertebral discs, which likely places them at higher risk of injury.

Ford et al. (2000) concluded that muscle maximum strength capacity diverges as height varies, indicating that there is a relationship between anthropometry and strength capability. They found that muscle strength approaches absolute maxima at height for females 175 cm and for males 183 cm. Finally, they suggested a possible relationship between strength and height. Thus, it can be said that individuals who fall in smaller percentile groups will have smaller anthropometric measurements (e.g. arm length, forward reach, elbow height, knuckle height, shoulder height) compared with individuals who represent upper percentiles (Figure 5). If an object is located on the floor but close to the body, individuals from lower percentiles may require less forward bending compared to higher percentile individuals, however, as the object goes far away from the body horizontally or the vertical height location of the object increases, then individuals with higher percentiles will likely require less forward bending, thus, reducing muscle effort and the risk of LBD.

Source: http://images.google.com

Figure 5. Two individuals representing lower and higher percentiles

2.4 ACGIH Lifting TLV

In 2001, the American Conference of Governmental Industrial Hygienists released a new lifting assessment method known as the ACGIH Lifting Threshold Limit Values (TLV). It was aimed to provide guidelines to protect virtually any individual when the lifting load is below the TLV® within a certain duration, frequency, and horizontal and vertical location of the task, protecting the individual from work-related shoulder and/or low back disorders (ACGIH 2009; Marras & Hamrick, 2006). If the TLV® is exceeded, changes in the work design should be applied such that the load weight lifted falls below the TLV weight.

This method used the latest scientific evidence, which is based from the NIOSH lifting equation, and TLVs resulted from the combination from the psychophysical studies of Snook and Ciriello (1991), now known as the Liberty Mutual Tables, and strength testing data for loads tolerable to 75% of females, using the 3DSSPP method (ACGIH, 2001). Moreover, it has been compared with other frequently used assessment methods and the results have shown that it correctly identified most of the known high risk jobs, similar to the NIOSH and Liberty Mutual Tables, (Russell et al. 2007). However, no formal studies have been performed for predictive validity, intra-observer, and inter-observer repeatability.

The ACGIH Lifting TLV assessment method consists of a set of three tables that takes into account the weight of the object, horizontal and vertical location of the object to be lifted at the origin, repetition, and duration of the lifting. In each table are 12 zones; four zones for the vertical height (floor to mid-shin, mid-shin to knuckle, knuckle to shoulder, and shoulder to reach limit) and three horizontal distance zones (close, intermediate and extended). Figure 6 gives more detail of the twelve zones (ACGIH, 2009 TLVs and BEIs; Marras & Hamrick, 2006).

The strengths of this method are that is quick and easy to use: Its format translates relatively complex data into a quick and easy to use assessment and interpretation of the results, helping the user when the TLV is exceeded to consider job redesign strategies. On the other hand, these lifting tables are limited to two-handed mono-lifting tasks with a maximum torso asymmetry of 30 degrees away from the sagittal plane. If any of the following conditions are present, professional judgment should be applied either to reduce the recommended weight limits or to propose a task redesign (ACGIH 2009; Marras & Hamrick, 2006):

- Lifting frequency exceeds 360 lifts per hour;
- Asymmetry greater 30 degrees (rotation in the sagittal plane);

- Lifting task duration greater than eight hours per day;
- One-handed lifting;
- Body posture different from standing, such as kneeling, seated, crouching, restricted head room;
- Working conditions under high temperatures and/or humidity (Note: ACGIH also provides Heat Stress and Stain TLVs which should be assessed before using this Method);
- Lifting unbalanced objects (anything that shifts the center of mass while lifting such as liquids, people, animals);
- Unstable footing (unable to hold the body with both feet while lifting such as slippery floor, unsteady ground/or surface);
- Poor hand coupling (no handles, cut-outs, poor hand holds, or other grasping points).

Bernard (2006) developed a modified version for each of the original ACGIH Lifting TLV tables named as "additional risk – Lower Screening Limit". These tables should be used when any of the limitations of this method are present, except for lifting frequencies that exceed 360 lifts per hour, asymmetry over 30 degrees, or lifting task over eight hours per day, where professional judgment has to be made. However, no validation of these modified ACGIH tables has been performed and in its 2009 ACGIH‟s Threshold Limit Values and Biological Exposure Indices book, these additional tables were not included.

Another limitation of this method is it is not suitable if other manual material handling, pushing, pulling, and/or carrying, activities are being performed while lifting.

This assessment method does not predict injuries, nor take into account individual factors such as gender, age, habits (e.g. smoking), or medical history (ACGIH, 2009 TLVs and BEIs Book; Marras & Hamrick, 2006). Additionally, this method, when was developed, only considered the lift origin and not the final destination. In 2007, the ACGIH suggested that if the load is placed in a controlled manner (i.e. slowly or consciously placed), the TLV® can be estimated in the same manner as at the origin, and to use the lowest TLV® among them. The challenge then becomes deciding when an uncontrolled placement of the load is present.

Finally, this assessment method doesn‟t explain or address what happens when the final destination of the object is different from its origin. In other words, this method only assesses the lift at the origin, and not the destination.

2.4.1 Procedures to Determine the Lifting Threshold Limit Value

To use this method, the weight of the object(s) to be lifted must be known, a tape measure used to measure the horizontal and vertical locations, and task information such as frequency and duration must be determined. The procedure to determine the TLV is as follows:

1) Determine task duration and lifting frequency of the task.
2) Select the proper TLV table (Tables 3-5) (Note: Table 2 helps to identify the appropriate ACGIH table for use based on frequency and duration).
3) Identify the lifting zone height according to the initial position of the hand, and the horizontal location of the lift (midpoint between the hands compared to midpoint between the ankles), (Figure 6).

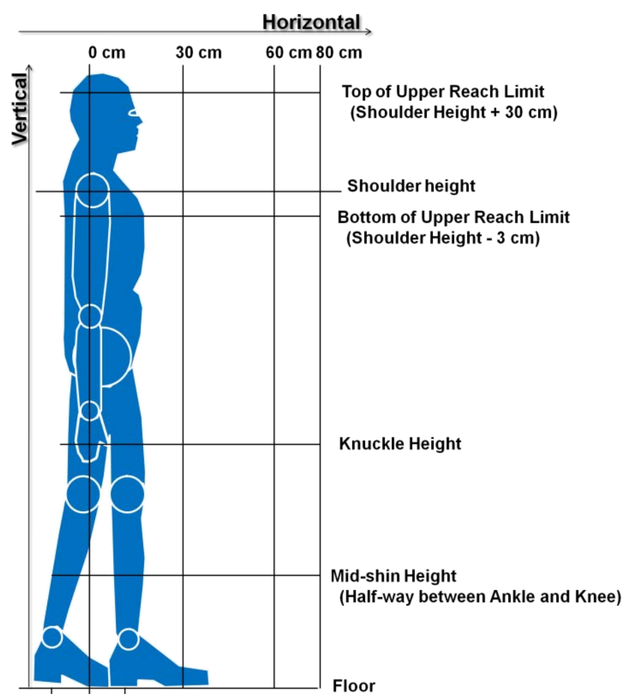
4) Determine the corresponding zone, then compare the lifted weight against the maximum recommended TLV and report the findings. If the lifted weight exceeds the TLV, an ergonomic intervention should be suggested and implemented such that the weight is less than the TLV.

TABLE 2

TABLE TO SELECT THE ADEQUATE ACGIH LIFTING TLV TABLE

	Duration of Task per day	
Lifts per hour	**≤ 2h**	**>2h**
≤ 60	Table 3	
≤ 12		Table 3
> 12 and ≤ 30		Table 4
> 60 and ≤ 360	Table 4	
> 30 and ≤ 360		Table 5

Source: Marras, 2006



Note: adapted from ACGIH, 2009 TLVs and BEIs Book.

Figure 6. Graphic representation of vertical and horizontal zones

TABLE 3

ACGIH LIFTING TABLE: INFREQUENT LIFTING

TLVs® for Infrequent Lifting:

≤ 2 Hours per Day with ≤ 60 Lifts per Hour
OR
≥ 2 Hours per Day with ≤ 12 Lifts per Hour

	Horizontal Zone[A]		
Vertical Zone	**Close: < 30 cm**	**Intermediate: 30 to 60 cm**	**Extended:**[B] **> 60 to 80 cm**
Reach limit[C] or 30 cm above shoulder to 8 cm below shoulder height	16 kg	7 kg	**No known safe limit for repetitive lifting**[D]
Knuckle height[E] to Below shoulder	32 kg	16 kg	9 kg
Middle shin to knuckle height[E]	18 kg	14 kg	7 kg
Floor to middle shin height	14 kg	**No known safe limit for repetitive lifting**[D]	**No known safe limit for repetitive lifting**[D]

Footnotes for Table 3 through 5:

A. Distance from midpoint between inner ankle bones and the load
B. Lifting tasks should not start or end at the horizontal reach distance more than 80 cm from the midpoint between the inner ankle bones (See Figure 7)
C. Routine lifting tasks should not start or end at heights that are greater than 30 cm above the shoulder or more than 180 cm above floor level (see Figure 7)
D. Routine lifting tasks should not be performed for shaded table entries marked "No known safe limit for repetitive lifting." While the available evidence does not permit identification of safe weight limits in the shaded regions, professional judgment may be used to determine if infrequently lifts of light weight may be safe.
E. Anatomical landmark for knuckle height assumes the worker is standing erect with arms hanging at the sides.

TABLE 4

ACGIH LIFTING TABLE: MODERATELY FREQUENT LIFTING

> 2 Hours per Day with > 12 and ≤ 30 Lifts per Hour
OR
≤ 2 Hours per Day with > 60 and ≤ 360 Lifts per Hour

	Horizontal Zone[A]		
Vertical Zone	**Close: < 30 cm**	**Intermediate: 30 to 60 cm**	**Extended:[B] > 60 to 80 cm**
Reach limit[C] or 30 cm above shoulder to 8 cm below shoulder height	14 kg	5 kg	**No known safe limit for repetitive lifting[D]**
Knuckle height[E] to Below shoulder	27 kg	14 kg	7 kg
Middle shin to knuckle height[E]	16 kg	11 kg	5 kg
Floor to middle shin height	9 kg	**No known safe limit for repetitive lifting[D]**	**No known safe limit for repetitive lifting[D]**
See Notes in Table 3			

TABLE 5

ACGIH LIFTING TABLE: FREQUENT, LONG DURATION LIFTING

> 2 Hours per Day with > 30 and ≤ 360 Lifts per Hour

	Horizontal Zone[A]		
Vertical Zone	**Close: < 30 cm**	**Intermediate: 30 to 60 cm**	**Extended:[B] > 60 to 80 cm**
Reach limit[C] or 30 cm above shoulder to 8 cm below shoulder height	11 kg	**No known safe limit for repetitive lifting[D]**	**No known safe limit for repetitive lifting[D]**
Knuckle height[E] to Below shoulder	14 kg	9 kg	5 kg
Middle shin to knuckle height[E]	9 kg	7 kg	2 kg
Floor to middle shin height	**No known safe limit for repetitive lifting[D]**	**No known safe limit for repetitive lifting[D]**	**No known safe limit for repetitive lifting[D]**
See Notes in Table 3			

2.5 Industrial Lumbar Motion Monitor

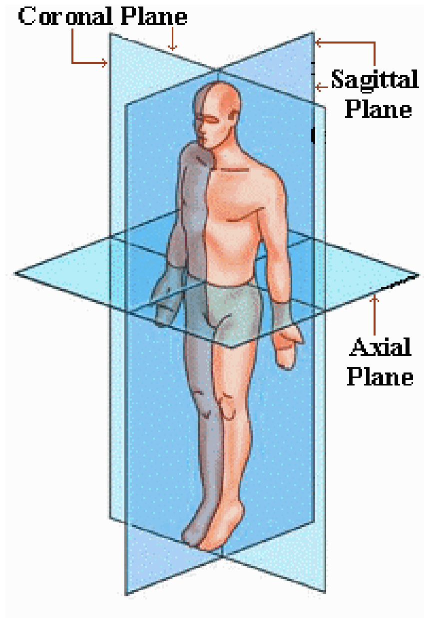
2.5.1 Overview

Kinematics are used in ergonomics and biomechanics to study and understand motion of body segments without taking into account the mass or forces leading to the motion. The Industrial Lumbar Motion Monitor (iLMM), shown in Figure 7, collects torso kinematics and translates into tangible information such as position (degrees), velocity (degrees/second), and acceleration (degrees/second^2) from each plane (sagittal, coronal, and transverse, shown in Figure 8).

The iLMM was developed in the Biodynamics Laboratory at The Ohio State University in response to the need for a quantitative method to assess the dynamic factors with job-related LBD risk in an industrial setting. The iLMM is a triaxial electrogoniometer which mimics the spine and records the instantaneous position of the torso relative to the pelvis, in the three planes through four rotary potentiometers located at the base of the equipment. It is attached on the back directly in line with the spine using a harness over the shoulders and a waist belt at the pelvis (Figure 9).

Source: http://www.nexgenergo.com/ergonomics/lumbarmm.html

Figure 7. Industrial Lumbar Motion Monitor device



Source http://images.google.com

Figure 8. Coronal, sagittal, and axial planes

Source: http://www.nexgenergo.com/ergonomics/lumbarmm.html

Figure 9. How the iLMM is worn and looks like once installed

2.6 Low Back Disorder Risk Model

Marras et al. (1993), in their cross-sectional epidemiological study of low back disorders, assessed over 400 industrial jobs, examining only repetitive tasks without job rotation. These jobs fell within two groups, and were considered either “low-risk” (no

LBD reported) or “high-risk” jobs (at least 12 LBDs reported per 100 workers per year). After collecting workplace (e.g. maximum external moment, average weight, and vertical location at origin) and personal factors (e.g. gender, anthropometry, and employee health), subjects were fitted with the iLMM to record torso motions (position, velocity, and acceleration from each plane). Results from the study concluded that the combination of five variables can predict the probability of high-risk group membership. These variables are:

- Workplace variables:
  - Maximum external moment about the spine;
  - Job"s lift rate;
- Torso motion variables:
  - Maximum sagittal flexion position;
  - Maximum lateral velocity;
  - Average twisting velocity.

The LBD Risk Model has the ability to predict the risk of low back injury virtually for any manual material handling (MMH) task (Marras & Allread, 2006). Marras et al. (2000) validated this risk model through a prospective epidemiological study. The LBD Risk model has a predictive power for the identification of high risk jobs for LBD three times higher than the 1991 NIOSH revised lifting equation (Marras et al. 1999).

The Biodynamics Laboratory from the Ohio State University (http://biodynamics.osu.edu) has used the iLMM extensively for their surveillance studies in fields such as manufacturing and healthcare (e.g. Allread et al. 2000;

Ferguson et al. 2004), and laboratory investigations regarding manual material handling (e.g. Marras et al. 2004; Korkmaz et al. 2006; Marras et al. 2006).

2.6.1 Data Collection and Analysis

First, detailed information regarding the job description needs to be gathered for the LBD Risk model such as load weight, horizontal moment arm, and lift frequency. Second, kinematic data (torso position, velocity, and acceleration) from each of the three planes are collected by the iLMM. Third, using the Ballet 2.0 software, the maximum moment, the lift rate, and the kinematic data are input into the model and compared against the database of jobs which returns a value that represents the probability that the job or task of interest is from a group of high risk jobs (i.e., probability of high risk group membership). The probability scale for the classification of risk is as follows (Marras et al. 2000):

- Low LBD risk ≤ 30%;
- Medium LBD risk >30% and ≤70%;
- High LBD risk > 70%.

2.6.2 Advantages and Disadvantages

The iLMM has many advantages, including the data collected with the iLMM allows it to be used in real-world work environments, it can address the overall LBD risk level and each of the risk factors separately to identify the type of job intervention that may be necessary to be assessed. This risk assessment method compares the analyzed task(s) with a database with known high risk LBD workplace factors and torso motions. Furthermore, this method has been validated (Marras et al., 2000).

On the other hand, this method requires training, employee willingness to cooperate and wear the iLMM, requires time, rental or purchase of the equipment and software, is difficult to use in narrow or confined spaces, and does not assess the risk of injury to other body parts (Stanton et al., 2006).

2.6.3 Applicability and Scope

Gill & Callaghan (1996) validated the iLMM‟s intratester and intertester reproducibility through a clinical trial. Also, they concluded that the iLMM was suitable to be used for evaluation in a research or clinical setting. The iLMM can be used virtually in any job where torso movements are involved to monitor position, velocity and accelerations in the sagittal plane for forward bending, coronal plane for side bending, and transverse plane for trunk rotation.

According to the distributor (NexGen Ergonomics, Montreal, Quebec, Canada) the iLMM can help ergonomists and researchers:

- Objectively evaluate the risk related to an MMH task;
- Obtain quick feedback as to the risk level of a MMH task;
- Identify the specific task(s) of a job most responsible for producing injury risk;
- Determine the level of risk injury from each task involved with MMH;
- Assess and quantify the impact of any ergonomic interventions.

CHAPTER 3

RESEARCH VOIDS AND OBJECTIVES

3.1 Research Voids

Several research voids were found regarding the ACGIH Lifting TLV method. First, the ACGIH Lifting TLVs may not appropriately address gender and/or anthropometric measurements in the lifting threshold limit values. Thus, it becomes necessary to analyze and compare the results from a controlled experiment utilizing the probability of the LBD risk using the iLMM by gender and different anthropometric categories.

Second, there may be a different LBD risk even when not exceeding the ACGIH Lifting TLV weight limit at different locations within the same zone. Therefore, it is of interest to test the same lifting TLV at different locations within the same zone. Finally, these tables were intended only for assessing lifting at the origin, without considering the location of the final destination. However, there may be cases where the destination may contain higher risk for LBD than the origin. Therefore, the ACGIH may underestimate the risk when only assessing the origin.

3.2 Research Objectives

Based on the research voids, the following research objectives were identified utilizing a validated measure of risk of LBD:

- Assess if differences in LBD Risk exist when the origin varies from the final destination when lifting the ACGIH‟s recommended weights (i.e., TLV‟s) in each zone.

- Assess if differences in LBD Risk exist when using the ACGIH‟s recommended lifting weights (i.e., TLV‟s) as a function of gender.
- Assess if differences in LBD Risk exist when using the ACGIH‟s recommended lifting weights (i.e., TLV‟s) as function of anthropometry.
- Assess if differences in LBD Risk exist when the ACGIH‟s recommended lifting weights (i.e., TLV‟s) are placed at different locations within the same horizontal zone.

3.3 Hypotheses

The following research hypothesis will be tested:

1. The lowest percentile group, 5^{th} to 34^{th}, from both genders will have the highest LBD Risk, especially for the horizontal distance of >60 to 80 centimeters (i.e., extended lift).
2. The highest percentile group, 65^{th} to 95^{th}, will have the lowest LBD Risk overall.
3. The female group will have a higher LBD Risk than the male group.
4. The LBD Risk will be different within the same horizontal zone due to differences in the external moment.

CHAPTER 4

METHODS

4.1 Approach

The experiment consisted of a series of different lifting conditions corresponding to one of the ACGIH Lifting TLV tables to determine if the weight limits that are suggested takes into account gender, anthropometry, and when the final destination of the object to be lifted varies from its origin. Figure 10 illustrates the setup of the experiment.

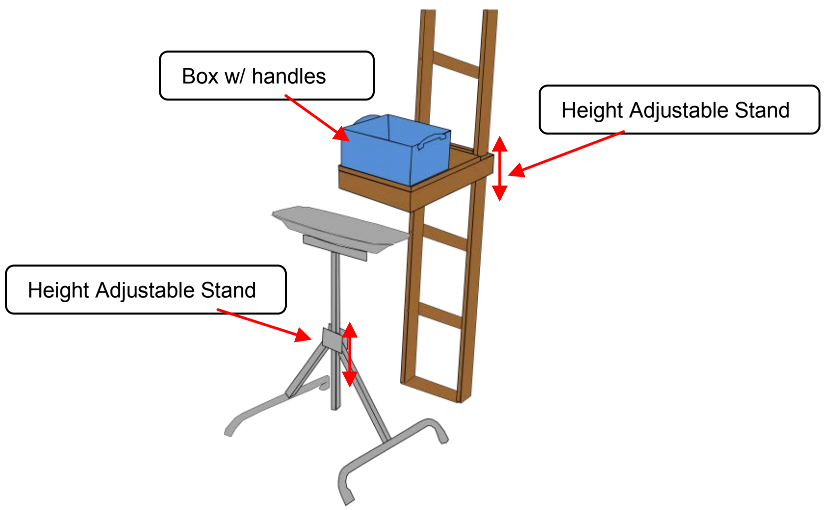


Figure 10. Experimental Setup

To protect the subjects from injury during the experimental trials, ACGIH‟s third table (see table 5) was selected, which is used for frequent and long duration lifting, and has the lowest recommended lifting weights. Additionally, this table is more likely to be used particularly within the manufacturing and distribution centers that have higher frequencies of lifting. In order to exclude twisting for the current evaluation and to test the hypothesis of acquire versus place, it was decided to add a mobile height adjustable stand to be the final destination of the lifted box. Therefore, this research was limited to the intermediate and extended horizontal zones. Moreover, Dempsey (2003) collected and evaluated 1063 lift and lowers, combined together, tasks from numerous industries across the continental United States, and after matching the horizontal distances with the ACGIH"s horizontal zones, it was found that the close zone (below 30 cm) was used by less than the 19th percentile, the intermediate zone (between 30 and 60 cm) is between the 19th and 88th percentile and extended zone (above 60 cm) used above the 88th percentile. This indicates that the intermediate horizontal zone is the most frequently used zone. Furthermore, from this table, reach limit of 30 cm above shoulder to 8 cm below shoulder height, and floor to middle shin height indicate "no known safe limit for repetitive lifting". Therefore, only four zones; two vertical, (knuckle to middle of shin height and below shoulder to knuckle height), and two horizontal zones, (intermediate 30 to 60 centimeters, and extended >60 to 80 centimeters), as shown on Table 6, were investigated.

TABLE 6

SELECTED ACGIH LIFTING TLV TABLE AND ZONES TO BE ASSESSED

> 2 Hours per Day with > 30 and ≤ 360 Lifts per Hour

Vertical Zone	Horizontal Zone[A]		
	Close: < 30 cm	Intermediate: 30 to 60 cm	Extended:[B] > 60 to 80 cm
Reach limit[C] or 30 cm above shoulder to 8 cm below shoulder height	11 kg	No known safe limit for repetitive lifting[D]	No known safe limit for repetitive lifting[D]
Knuckle height[E] to Below shoulder	14 kg	9 kg	5 kg
Middle shin to knuckle height[E]	9 kg	7 kg	2 kg
Floor to middle shin height	No known safe limit for repetitive lifting[D]	No known safe limit for repetitive lifting[D]	No known safe limit for repetitive lifting[D]
See Notes in Table 3			

To test if there is a difference in the LBD Risk when lifting from different locations within the same horizontal zone, participants were asked to lift the same weight from two different horizontal distances within each zone, separated by 10 centimeters (figure 11). In order to have the same distance among all the four horizontal distances, the load location was separated by 10 centimeters, which included 45, 55, 65, and 75 centimeters away from the midpoint between the ankles. For the middle shin to knuckle vertical zone, the load height was at the knee. For the knuckle height to below shoulder vertical zone, the load height was at the elbow. Since the waist height is the boundary from both studied vertical heights, it was used for the final destination height.

The anthropometric data used in this research came from the 2008 National Health Statistics report for children and adults in the United States for the years 2003-2006 completed by McDowell et al. (2008) (see appendix B for the tables). Since the ACGIH utilizes body landmarks to set the vertical zones, the anthropometric groups were determined according to the height of the subjects. In addition, it was decided to use the values that include all ethnicities to prevent any bias when selecting the participants. Percentiles below the 5^{th} and above the 95^{th} are not commonly used for design purposes since few people fall in these ranges. Thus, the anthropometric measurements for this study involved individuals who were between the 5^{th} and 95^{th} percentile. This range was divided into three groups for the purpose of this study. Refer to Table 7 for the anthropometric group division.

TABLE 7

ANTHROPOMETRIC GROUPS AS A FUNCTION OF HEIGHT AND GENDER

Females	**Percentile Range**	**Height Interval [cm]**
Group 1	$5^{th} - 35^{th}$	150.6 – 159.5
Group 2	$35^{th} - 65^{th}$	159.5 – 164.8
Group 3	$65^{th} - 95^{th}$	164.8 – 173.2

Males	**Percentile Range**	**Height Interval [cm]**
Group 1	$5^{th} - 35^{th}$	163.6 – 173.2
Group 2	$35^{th} - 65^{th}$	173.2 – 179.5
Group 3	$65^{th} - 95^{th}$	179.5 – 188.7

This research collected, analyzed and compared the probability of high-risk group membership (i.e., LBD Risk) for the ACGIH recommended weight limits for two vertical zones and two horizontal zones, with two lifting locations within each horizontal zone, making a total of eight lifting locations. The torso kinematic data were measured through the iLMM attached to the back of the participant while performing the lifting tasks.

4.2 Participants

Nine males and nine females without any activity limiting low back pain for at least the last six months volunteered to participate in this study. These participants represented the three anthropometric groups shown in Table 7. All participants were college students, most likely without any industrial manual material handling experience. All participants were briefed regarding the experimental trials, and read and signed an informed consent form approved by the Wichita State University Internal Review Board for Human Subjects. Table 8 summarizes participant‟s anthropometric and demographic information.

TABLE 8

PARTICIPANTS" SUMMARY PRESENTED BY GENDER AND PERCENTILE GROUP

Gender	Percentile Group	Height [cm]	Weight [kg]	Age [Years]
Female	5^{th} – 35^{th}	157.2 (2.4)	52.9 (2.9)	25.7 (2.9)
	35^{th} – 65^{th}	163.7 (1.0)	61.9 (11.8)	20.7 (0.6)
	65^{th} to 95^{th}	169.4 (0.1)	61.3 (8.1)	24.7 (2.1)
	Overall	163.5 (5.4)	58.7 (8.5)	23.7 (2.9)
Male	5^{th} – 35^{th}	170.0 (3.4)	78.5 (2.6)	27.3 (0.6)
	35^{th} – 65^{th}	176.4 (1.7)	78.1 (12.4)	33.0 (13.9)
	65^{th} to 95^{th}	183.6 (3.5)	77.1 (8.2)	26.3 (2.5)
	Overall	176.7 (6.5)	77.9 (7.6)	28.9 (7.7)

4.3 Experimental Design

For this experiment, the independent variables consisted of the anthropometry group, gender, and the location of the box within each horizontal and vertical location. The dependent variable consisted of the LBD Risk. Controlled variables were the asymmetry of 0 degrees at a lifting rate of four lift per minute, with repetitions of four times per lifting condition.

4.4 Equipment

The experimental lifting tasks for this experiment were performed using a height adjustable wooden shelf, for the mid-shin to knuckle height, the height was fixed to 66.0

cm, and for the knuckle to shoulder height, the height of the handles of the box was adjusted to each individual‟s elbow height. An adjustable stand was set about each individual‟s waist height, and a plastic box with handles to vary the weight to be lifted in each zone The box measured 35.6x25.4x14.0 centimeters and weighed approximately 0.4 kilograms by itself. The remaining load was filled with bags of 1kg each. A chronometer was used to control the lifting frequency and a voice command to perform the trial lifting sequence, at the predetermined time interval. The measurement equipment used to collect the three dimensional torso kinematics of each individual consisted of an iLMM, and a tape measure was used to measure the horizontal moment arm from the approximate location of the L_5/S_1 intervertebral disc to the midpoint between the hands holding the box, at the origin and destination of the lift.

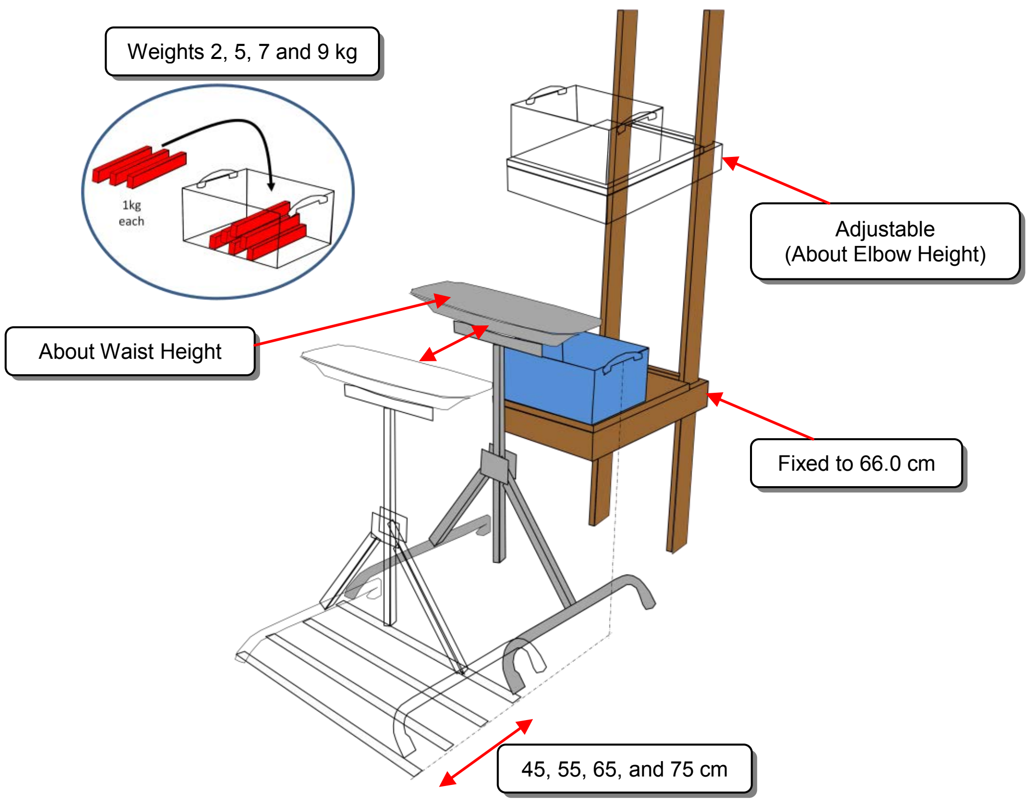
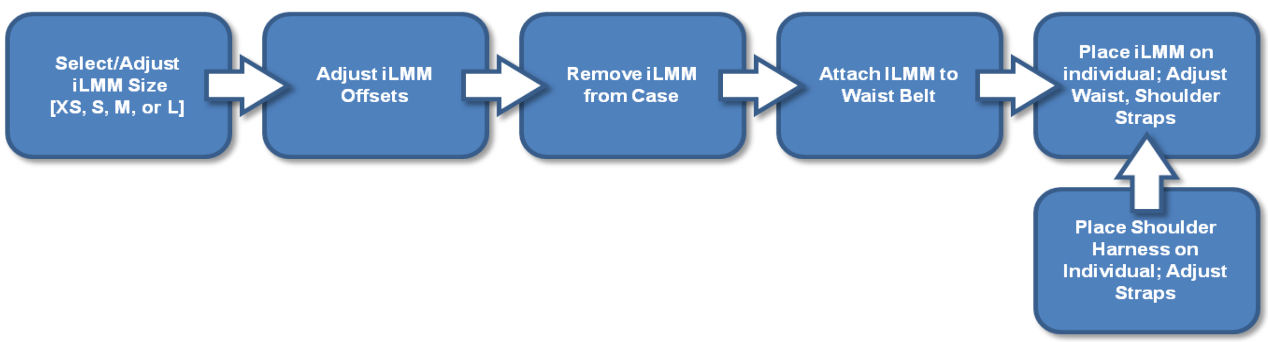


Figure 11. Experimental setup with horizontal and vertical distances

and investigated TLV‟s

4.5 Experimental Protocol

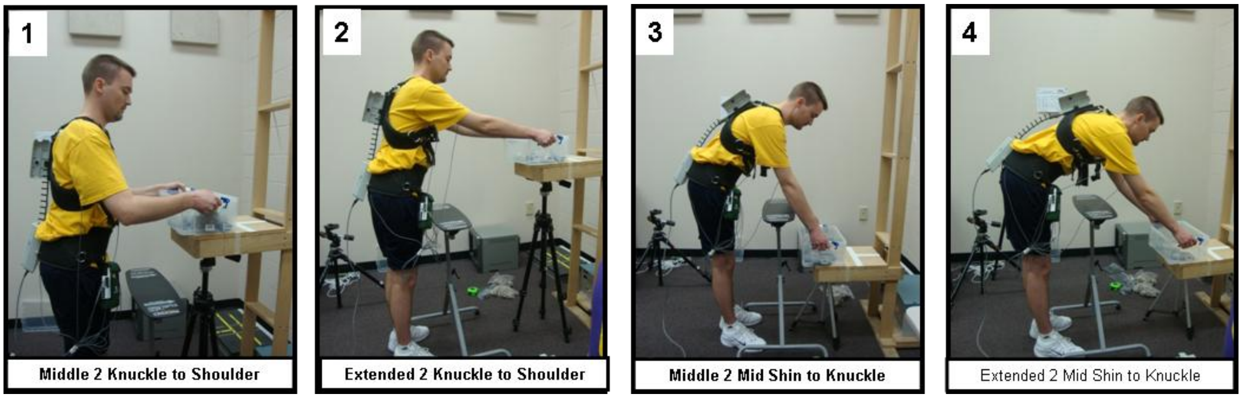
After signing an informed consent form and agreeing to participate in the study, the participant"s height and weight measurements were collected. Following the anthropometry measurement, the participant was fitted with the iLMM (Figure 12 summarizes the procedure). The participant was then given a warm-up period to allow familiarization with the lifting trials and the instructions of the tasks that they were expected to perform. Any concerns from the participants prior to the experiment were addressed. The experimental task consisted of lifting a box with handles from randomly selected combinations of two vertical and four horizontal locations, to a fixed destination adjusted to the participant"s waist height. Subjects acquired and placed the box four times from each combination of vertical height and horizontal location, with a complete interval of 15 seconds each time.



Note: Adapted from Marras & Allread, 2006.

Figure 12. Flow chart of the setup of the iLMM

For each trial the iLMM recorded the torso kinematics data when the participant started to acquire the box at the origin and stopped when the box was positioned at the destination. Participants were not allowed to move their feet in order not to add another variable in the research and create variability between each participant. Figure 13 illustrates how the different body parts are exerted when acquiring the box at different horizontal and vertical locations. Figure 14 shows a lifting trial sequence of a complete interval from start to end of a cycle.



Note: Pictures 1 and 2 illustrates the acquiring difference between middle 2 and extended 2 horizontal distances at elbow height, where pictures 3 and 4 illustrates acquiring difference between middle 2 and extended 2 horizontal distances at knee height.

Figure 13. Experimental Setup at different locations

Figure 14. Experimental lifting trial sequence

4.6 Data Analysis

The input data that the iLMM"s software, Ballet 2.0™ (NexGen Ergonomics Inc., Pointe Claire (Montreal), Quebec, Canada), required to analyze for the experiment for each lifting location included the moment arm at origin and destination, load weight, and lifting frequency. Through the iLMM, the software recorded for each of the three planes torso position (deg), velocity (deg/sec), and acceleration (deg/sec^2). Once all the required data were collected, the software used a logistic regression model to estimate the probability of the LBD high risk group membership (i.e., LBD Risk). It was configured to analyze the four repetitions and display the LBD Risk for each participant per direction, for each combination of horizontal location and vertical lift height (Figure 15).

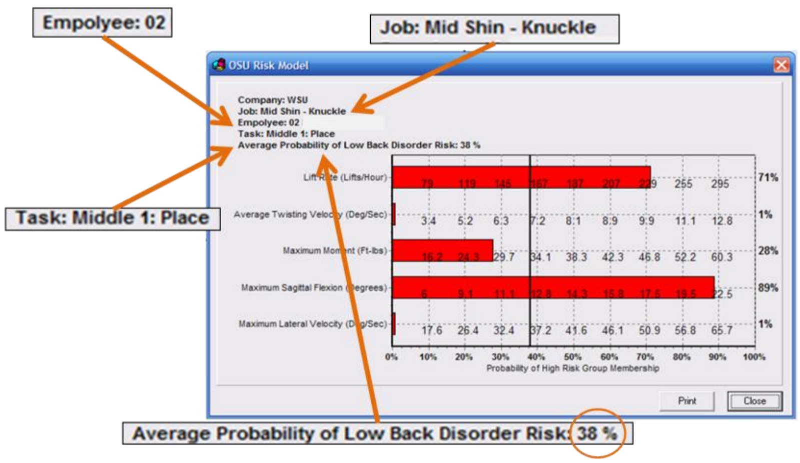


Figure 15. Ballet 2.0 LBD Risk analysis from screen

4.7 Statistical Analyses

In order to determine if there were any significant differences in the LBD Risk and/or interaction among any of the independent variables, Analysis of Variance (ANOVA) was conducted using SAS statistical software (SAS 9.1, Cary, NC). Each independent variable had different levels, **direction**: acquire and place; **gender:** female and male; **anthropometry**: groups 1, 2, and 3; **horizontal**: middle 1, middle 2, extended 1, and extended 2; and **lift height**: mid-shin to knuckle and knuckle to shoulder. When an independent variable was significant, a Tukey's Studentized Range (HSD) post-hoc test was utilized. An alpha (α) of 0.05 was used to protect against committing a Type I error. Significant two way interactions were investigated utilizing the Least Significant Difference post-hoc test, using a Bonferroni adjustment to α for the number of pairwise comparisons.

CHAPTER 5

RESULTS

5.1 Experimental Study Results

The terms utilized in the study are the following: **Horizontal** was used to address the four horizontal locations (middle 1, middle 2, extended 1, and extended 2); **Direction** was used for acquire and place; **Gender** was used for male and female; **Anthropometric group** was used for the three anthropometric height categories used to divide each gender; and **Lift height** was used for mid-shin to knuckle and knuckle to shoulder vertical heights.

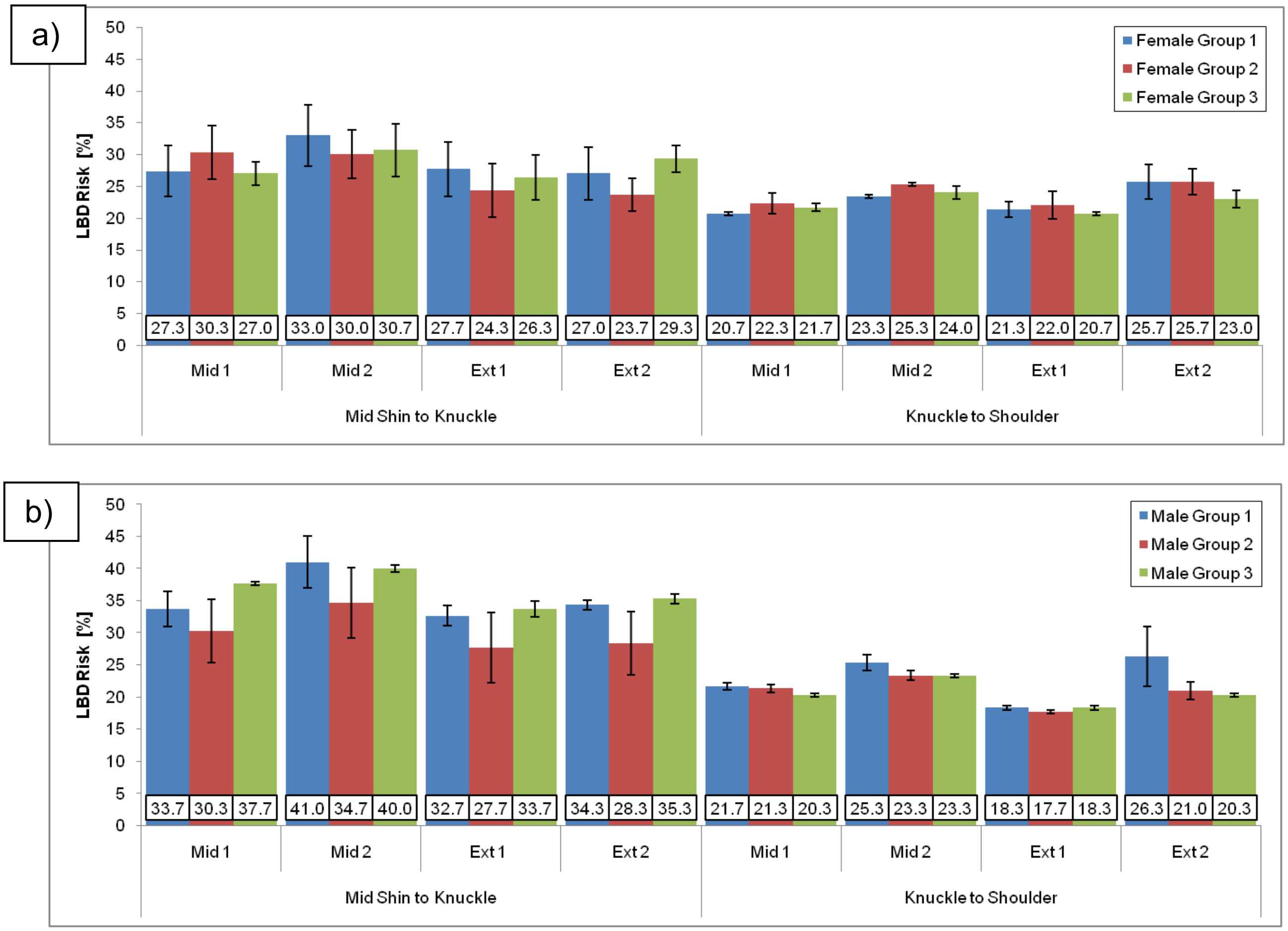
5.2 LBD Risk

Descriptive statistics for the LBD Risk are presented in table 9 by gender, anthropometry group, horizontal locations, and vertical height. Figure 16 displays table 9‟s results divided by gender.

TABLE 9

MEAN (SD) LBD RISK AS A FUNCTION OF GENDER, ANTHROPOMETRIC GROUP, HORIZONTAL AND VERTICAL LOCATIONS

Gender	**Anthropom. Group**	**Mid Shin to Knuckle**				**Knuckle to Shoulder**			
		Mid 1	Mid 2	Far 1	Far 2	Mid 1	Mid 2	Far 1	Far 2
Female	1	27.3 (8.0)	33.0 (9.6)	27.7 (8.5)	27.0 (8.2)	20.7 (0.6)	23.3 (0.6)	21.3 (2.5)	25.7 (5.5)
	2	30.3 (8.5)	30.0 (7.6)	24.3 (8.5)	23.7 (5.1)	22.3 (3.2)	25.3 (0.6)	22.0 (4.4)	25.7 (4.0)
	3	27.0 (3.6)	30.7 (8.3)	26.3 (7.1)	29.3 (4.2)	21.7 (1.2)	24.0 (2.0)	20.7 (0.6)	23.0 (2.6)
Male	1	33.7 (5.5)	41.0 (8.0)	32.7 (3.2)	34.3 (1.5)	21.7 (1.2)	25.3 (2.5)	18.3 (0.6)	26.3 (9.2)
	2	30.3 (9.9)	34.7 (11.0)	27.7 (11.0)	28.3 (9.8)	21.3 (1.2)	23.3 (1.5)	17.7 (0.6)	21.0 (2.6)
	3	37.7 (0.6)	40.0 (1.0)	33.7 (2.5)	35.3 (1.5)	20.3 (0.6)	23.3 (0.6)	18.3 (0.6)	20.3 (0.6)



Note: Mid refers to middle zone and ext. to extended zone.

Figure 16. LBD Risk presented by horizontal distance and gender;

a) females and b) males

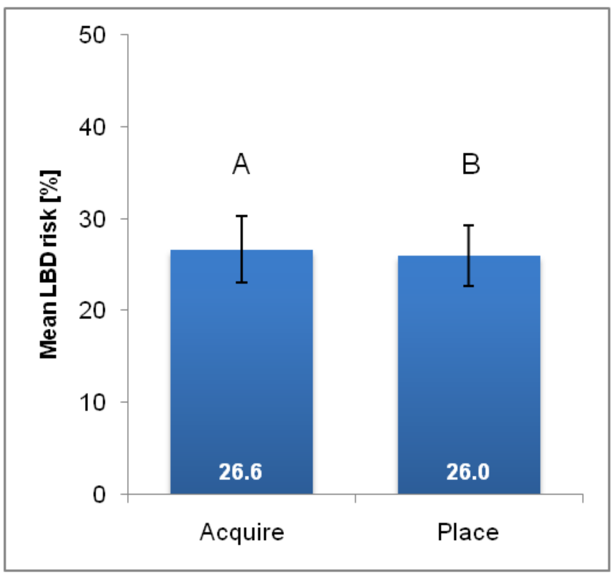
5.2.1 Acquire and Place LBD Risk

To address the question if there is a difference in LBD Risk between acquiring and placing an object (i.e. Direction) a three-way repeated measures ANOVA was performed, with Direction, Horizontal location, and Lift Height, used as independent variables. There was a statistical difference in LBD Risk as a function of the direction of the lift (p=0.038), whereas there were no significant interactions between direction and horizontal location (p=0.8244) and direction and lift height (p=0.3799). Table 10 summarizes the ANOVA results. As shown in figure 17, the LBD Risk for acquiring the load was 26.6%, and placing the load was 26.0%. Although the difference was statistically different, the magnitude of the difference was very small.

TABLE 10

ANOVA FOR DIFFERENCE BETWEEN ACQUIRE AND PLACE ON LBD RISK

Source	p-value	Observations
Direction	0.0380	Significant
Horizontal	<0.0001	Significant
Lift Height	<0.0001	Significant
Direction × Horizontal	0.8244	Not Significant
Direction × Lift Height	0.3799	Not Significant



Note: Means with the same letter are not significantly different

Figure 17. LBD Risk as a function of acquiring and placing the load

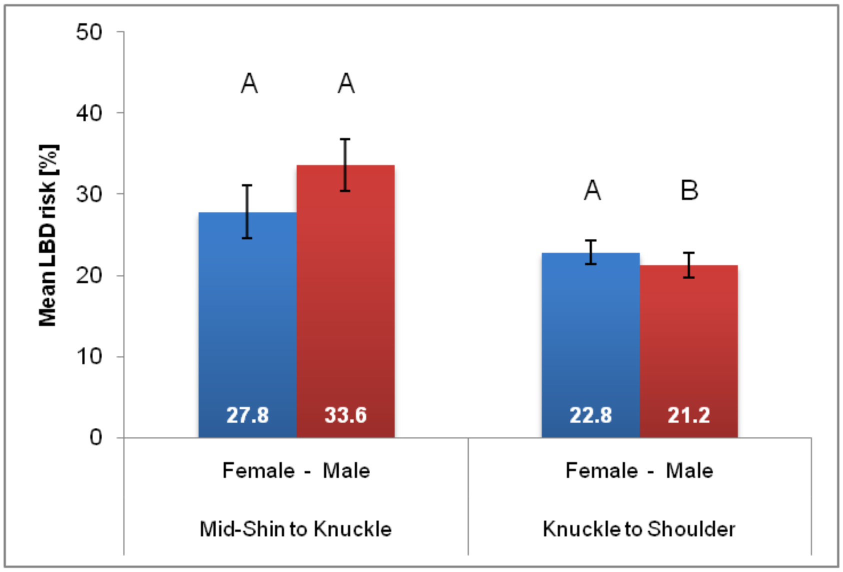
5.2.2 Gender LBD Risk

To address the question if there is a difference in LBD Risk as a function of gender, a two-way repeated measures ANOVA was performed separately for each vertical height, combining acquire and place trials since there was very little difference in LBD Risk between these two directions. The independent variables included Gender and Horizontal location. Results showed that for the mid-shin to knuckle height, gender did not have a significant effect on LBD Risk (p=0.0515). For the knuckle to shoulder height, LBD Risk varied significantly as a function of gender (p=0.0129). Additionally, gender did not interact with horizontal distance significantly for either lifting height (p=0.9098, p=0.2063). Table 11 summarizes the ANOVA results. As shown in Figure 18, the mean LBD Risk for males and females at mid-shin to knuckle height was 33.6% and 27.8%, respectively, although this difference was not significant. For lifting in the knuckle to shoulder vertical zone, the mean LBD risk for males and females was 21.2% and 22.8%, which was significantly different, although the magnitude of the difference was rather small.

TABLE 11

ANOVA FOR DIFFERENCE BETWEEN GENDERS ON LBD RISK

Source		p-value	Observations
Mid-Shin to Knuckle	Gender	0.0515	Not Significant
	Horizontal	<0.0001	Significant
	Horizontal × Gender	0.9088	Not Significant
Knuckle to Shoulder	Gender	0.0129	Significant
	Horizontal	<0.0001	Significant
	Horizontal × Gender	0.2063	Not Significant



Note: Means with the same letter are not significantly different

Figure 18. LBD Risk as a function of gender

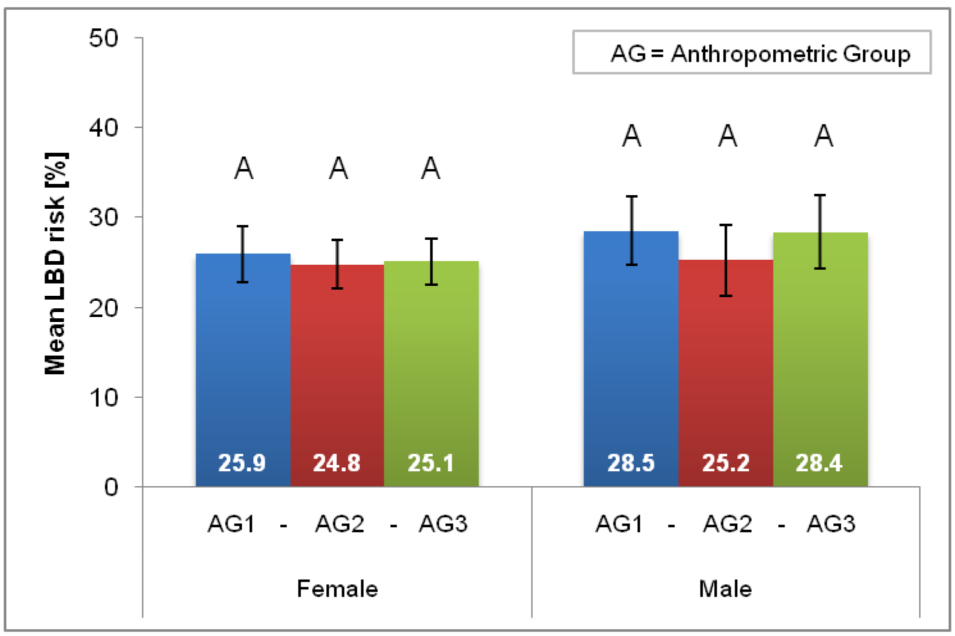
5.2.3 Anthropometric Group LBD Risk

To address the question if there is difference in LBD Risk as a function of anthropometry and horizontal location of the load, a two-way repeated measures ANOVA was performed separately for each gender. The different direction and lift height trials were combined. For females, anthropometry did not have a significant effect on LBD Risk (p=0.9225), nor did LBD Risk vary significantly as a function of anthropometry at the different horizontal locations (p=0.3817). Similarly, for males, the effect of anthropometry on LBD Risk was not significant (p=0.4565), nor as a function of anthropometry at the different horizontal locations (p=0.0745). Table 12 summarizes the ANOVA results. As shown in Figure 19, the LBD Risk for females ranged between 24.8% and 25.9% across the different anthropometry groups. For males, the LBD Risk ranges between 25.2% and 28.5% across the different anthropometry groups.

TABLE 12

ANOVA FOR DIFFERENCE IN ANTHROPOMETRIC GROUPS FROM EACH GENDER ON LBD RISK

Source	p-value	Observations
Female		
Anthropometric Group	0.9225	Not Significant
Horizontal	0.0001	Significant
Horizontal × Anthropometric Group	0.3817	Not Significant
Male		
Anthropometric Group	0.4546	Not Significant
Horizontal	<0.0001	Significant
Horizontal × Anthropometric Group	0.0745	Not Significant



Note: Means with the same letter are not significantly different

Figure 19. LBD Risk as a function of anthropometry for each gender

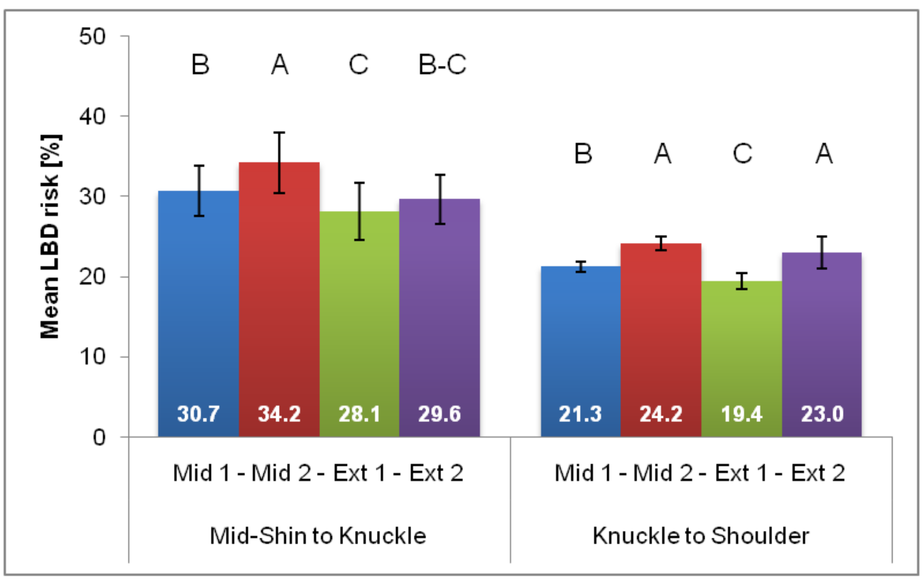
5.2.4 Horizontal Location LBD Risk

To address the question if there is a difference in LBD Risk as a function of the horizontal location, a one-way repeated measures ANOVA was performed separately for each vertical lift height, where gender and direction trials were combined. For the mid-shin to knuckle height vertical zone, middle 1-extended 2 and extended 1- extended 2 showed no significant difference (Figure 20). As for the knuckle to shoulder horizontal zones, middle 2-extended 2 showed no significant difference (Figure 20). Table 13 summarizes the ANOVA results. As shown in Figure 20, the LBD Risk for the mid-shin to knuckle height the LBD Risk ranges between 28.1% and 34.2% across the different horizontal distances. For the knuckle to shoulder height, the LBD Risk ranges between 19.4% and 24.2%.

TABLE 13

ANOVA FOR DIFFERENCE AMONG SAME ZONE ON LBD RISK

Source	**p-value**	**Observations**
Mid-Shin to Knuckle: Horizontal	<0.0001	Significant
Knuckle to Shoulder: Horizontal	<0.0001	Significant



Note: Means with the same letter are not significantly different

Figure 20. LBD Risk as a function of the horizontal zone and lift height

CHAPTER 6

DISCUSSION

Low back disorders remains the top musculoskeletal disorder across several industries, where lifting is commonly associated as a major risk factor in the workplace. Researchers have developed numerous assessment methods to identify high-risk jobs, where the ACGIH lifting assessment method one of the most recent methods. It is the result of the combination of other frequently applied assessment methods, NIOSH, Liberty Mutual Tables, and 3DSSPP. Russell et al. (2007) applied the previously mentioned assessment methods to a mono-lifting case study, concluding that the ACGIH, NIOSH and Liberty Mutual methods were similar in their results. However, the ACGIH method has not been evaluated for its effectiveness regarding lifting the suggested Threshold Limit Values (TLVs®) among gender, difference in anthropometry, and if the lifting weight limits were appropriate at different horizontal locations within the same zone. Therefore, the ACGIH method was subject to evaluation using a validated measure of risk of LBD (Marras et al., 1993, 2000).

The ACGIH method has not been extensively analyzed, compared and/or validated. The only known published study was by Russell et al. (2007) for lifting and lowering milk cases, where they assessed and compared the results along with the NIOSH, Liberty Mutual, ACGIH, 3DSSPP, and the Washington lifting calculator with the likelihood of correctly identifying low, medium, and high levels of exposure. Similar results were obtained compared to the NIOSH and Liberty Mutual for the ACGIH correctly identifying the high risk jobs. The current research was performed in a laboratory assessing the ACGIH TLVs in four zones against the LBD Risk model to determine if the suggested lifting weight limits (i.e., TLV‟s) fell within a low risk category membership, and to assess if variables such as gender and anthropometry, which aren‟t taken into account by the ACGIH method, are important variables that should be considered.

The results of this study indicated that the overall LBD Risk of the ACGIH, irrespective of gender, anthropometry differences, or direction, in the knuckle to shoulder vertical zone, fell within the low risk category, for both middle and extended horizontal distances (22.7% and 21.7%, respectively). In the mid-shin to knuckle vertical zone, the LBD Risk values fell in the low- and medium-risk groups for both middle and extended horizontal distances (33.0% and 29.2%, respectively), Although the middle horizontal zone resulted in LBD Risk value of 33.0%, which is in the medium risk category, it is slightly elevated above the low risk category. Overall, although the TLV loads in each zone were different, the resulting probability of high risk group membership for each of the zones indicated the TLV weights represent low risk for LBD, for the frequency and duration that were investigated.

When comparing if there was a difference between acquiring and placing the same load (e.g. can the TLV be used to assess the destination as well as the origin), regardless of gender or anthropometry, although the difference was statistically different, the magnitude was very small (26% and 26.6%). Thus, at least for the zones investigated, it appears that the ACGIH TLV can be used to assess both the origin and the destination of the lift. The difference in LBD Risk as function of gender was not significant, where in the mid-shin to knuckle height males were slightly higher than females (33.6% compared to 27.8%), but in the knuckle to shoulder height were about the same (22.8% and 21.2%). Thus, for the zones investigated, LBD risk was found to be independent of gender.

When analyzing the anthropometric difference from each gender, regardless of horizontal or vertical location of the load, neither male nor female anthropometry groups were significantly different in terms of the LBD Risk. The female group obtained a mean LBD Risk probability about 25% (24.8% to 25.9%), and males obtained a mean LBD Risk probability about 27% (25.2% to 28.5%). Thus, for the zones investigated, LBD Risk was found independent of anthropometry.

When analyzing the LBD Risk as a function of the horizontal location in each zone, irrespective of gender or anthropometry, when the load travels from one location to another within the same zone, the most distant location from each zone resulted in somewhat higher LBD Risk probability values, with difference ranging from 1.5% to 3.5% higher for the further location in each horizontal zone compared to the closer horizontal location. However, the LBD Risk values were in the low risk category (i.e., <30%) in the knuckle to shoulder height, and slightly above the low risk – moderate risk threshold for the mid-shin to knuckle height depending on the horizontal location. When assessing the LBD Risk values at all four horizontals locations, it can be noticed that the load lifting reduction in the TLVs for the extended zone compared to the middle zone compensates for the increase in the moment, resulting in similar LBD Risk values. Thus, this suggests that there is no need to modify the horizontal locations proposed by the ACGIH.

Several limitations for this research can be identified. First, the iLMM collects only torso motion in the three planes and not the muscle activity from the torso muscles.

It was noticed that when some participants kept their back straight and used their knees, the LBD Risk probability was lower, but other body parts may be at elevated risk, such as the knees. Second, only the TLVs for the frequent ACGIH lifting Table were investigated and not the other two tables, which may result in different outcomes. Third, the population that participated was college students with little to no work-related lifting experience. Fourth, the anthropometric tables used to divide the groups" may be subject of discussion since the height deviation from the females were relatively small compared with the male deviation, and the industry workforce anthropometry, mainly for manual material handling task, may be different and have a different height distribution. Fifth, this research was generic in scope and may require replicating real world scenarios to make a comparison with this study to corroborate the findings. Sixth, the study was based on a statistical validated method instead of a biomechanical joint load for low back and shoulder, which may result in different findings. Finally, velocity of lift, twisting, obesity, psychological conditions, and lifting technique was not studied and may influence the difference in the variability of the results.

CHAPTER 7

CONCLUSIONS

The ACGIH lifting TLVs table for frequent lifting tasks appears to be appropriate to be applied regardless gender or anthropometry in the workplace environment with similar lifting conditions as described in the method. The strength of this method is that it is easy to use, only requires basic training on knowing how to measure distance and height. In places where there is limited budget for ergonomics and safety, this method provides information when a job redesign should be taken into account in order to reduce the LBD risk.

The study results showed that the ACGIH lifting TLVs for frequent lifting is independent from gender or anthropometry. Moreover, the LBD Risk at different locations in each horizontal zone are similar, thus there appears no need to add more horizontal zones to make this assessment method more specific. This study has also demonstrated that the LBD Risk can increase when the lift height is different from the knuckle to shoulder height (i.e., mid-shin to knuckle) and therefore requires a reduction in the TLV weight limit in order to keep the LBD risk low. In addition, the ACGIH lifting TLVs may be appropriate to assess both the origin and the destination, where the lowest TLV should be used as the weight limit for the lifting task.

This method is suggested mainly to be used as a screening tool to determine which areas or task need to be address first, but professional judgment and expertise is required to make a complete assessment of the task due that some other risk factors maybe present but is not estimated by this methodology.

CHAPTER 8

FUTURE RESEARCH

The remaining two ACGIH lifting TLVs tables should be analyzed in similar laboratory conditions to determine the LBD Risk. This method should be evaluated in different work environments to determine if it is practical to be used, or is restricted to be utilized in certain areas. Variables such as twisting and final destination (different than origin) should be included in the future research.

The usage of this method may increase if it is found a manner how to address when an object doesn"t provide handles, like delivery boxes, and when combining with another manual material handling task. It should be an interest of study to determine what happens it is lifted a weight that at the origin is below the TLV and the object is place in another location were exceeds it. The combination of electromyography and the LBD Risk probability may result in the best approach to fully determine if a given task may lead to elevated risk of injury or not.

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APPENDICES

APPENDIX A

Non Fatal Occupational Injuries Statistics, 2007

Number of nonfatal occupational injuries and illnesses involving days away from work by selected injury or illness characteristics and major industry sector (2007)

TABLE 5. **Number of nonfatal occupational injuries and illnesses involving days away from work[1] by selected injury or illness characteristics and major industry sector, 2007**

Characteristic	Private industry[2,3,4]	Goods producing				Service providing							
		Total goods producing	Natural resources and mining[2,3]	Construction	Manufacturing	Total service providing	Trade, transportation and utilities[4]	Information	Financial activities	Professional and business services	Education and health services	Leisure and hospitality	Other services
Total cases	1,158,870	349,450	26,900	135,350	187,200	809,420	359,770	18,560	35,450	88,260	181,700	94,160	31,520
Nature of injury or illness:													
Sprains, strains, tears[5]	448,380	115,870	8,650	44,380	62,840	332,510	150,290	7,340	12,520	33,040	90,710	29,320	9,290
Bruises, contusions	101,340	26,460	2,760	8,380	15,320	74,870	34,650	1,620	2,030	7,760	16,440	9,750	2,630
Cuts, lacerations	91,270	36,480	2,150	15,560	18,770	54,790	25,280	820	2,250	5,480	5,170	12,920	2,870
Punctures	15,730	8,670	380	4,820	3,480	7,060	3,250	90	150	1,480	1,120	570	410
Fractures	94,950	37,990	3,840	17,350	16,800	56,960	27,430	1,540	2,700	6,260	9,810	6,770	2,440
Heat burns	17,490	4,920	280	1,250	3,390	12,570	2,890	80	170	600	1,670	6,530	630
Carpal tunnel syndrome	11,940	4,510	60	280	4,170	7,420	3,100	300	830	1,430	1,310	290	180
Tendonitis	4,380	1,750	60	320	1,370	2,630	900	80	90	470	660	340	90
Chemical burns	6,130	2,240	230	540	1,470	3,890	1,040	–	450	320	700	1,170	200
Amputations	7,320	4,310	340	870	3,090	3,010	1,390	20	120	270	180	690	330
Multiple traumatic injuries	46,820	15,090	960	6,750	7,380	31,730	13,690	970	1,330	4,030	7,510	2,740	1,460
Part of body affected by the injury or illness:													
Head	78,370	26,920	2,400	10,590	13,930	51,450	23,370	1,090	2,640	5,960	8,510	7,210	2,680
Eye	33,010	14,550	1,200	5,200	8,150	18,460	8,320	260	1,220	1,960	2,240	2,700	1,750
Neck	17,050	4,080	300	1,870	1,920	12,960	5,880	170	730	1,470	3,440	730	550
Trunk	384,650	107,190	7,950	41,210	58,020	277,460	128,270	5,530	10,610	26,940	74,330	23,900	7,890
Shoulder	75,580	23,360	1,400	8,220	13,740	52,220	26,930	1,030	1,470	4,850	12,310	4,270	1,360
Back	235,960	58,060	4,340	22,600	31,120	177,900	78,070	3,380	7,010	16,980	52,640	14,610	5,210
Upper extremities	269,240	99,360	5,590	31,830	61,930	169,880	72,350	3,420	7,710	20,270	29,090	28,160	8,880
Arm	54,260	17,740	1,160	6,880	9,700	36,520	16,470	700	1,700	3,500	6,790	4,430	2,930
Wrist	51,620	14,930	530	3,770	10,630	36,690	14,740	980	2,220	5,480	7,730	4,410	1,110
Hand, except finger	47,920	18,550	1,000	7,490	10,060	29,370	12,330	550	1,100	3,480	4,230	6,170	1,500
Finger	101,650	43,750	2,610	12,530	28,610	57,900	25,350	940	2,230	6,510	8,120	11,810	2,930
Lower extremities	260,580	76,710	7,500	34,340	34,880	183,860	85,420	4,380	8,030	19,800	36,620	22,810	6,800
Knee	94,500	26,660	2,530	11,920	12,210	67,830	29,390	1,600	2,890	6,680	15,510	8,770	3,000
Ankle	62,660	16,700	1,520	8,490	6,690	45,960	20,630	1,080	1,740	5,730	9,060	6,130	1,590
Foot, except toe	43,970	14,570	1,520	5,870	7,170	29,400	14,950	660	1,630	2,940	4,930	3,460	840
Toe	11,630	3,680	220	1,590	1,870	7,950	4,990	250	170	470	1,180	550	340
Body systems	17,710	4,060	260	1,600	2,200	13,640	5,110	710	700	2,150	2,830	1,200	950
Multiple parts	120,950	28,700	2,630	12,900	13,170	92,250	35,800	3,130	4,420	10,950	25,420	9,210	3,300

Source: Bureau of Labor Statistics (BLS)

Number of nonfatal occupational injuries and illnesses involving days away by selected injury or illness characteristics and major industry sector (2007)

[This table was reissued in March 2009. See note at end of table.]

TABLE 5. **Number of nonfatal occupational injuries and illnesses involving days away from work[1] by selected injury or illness characteristics and major industry sector, 2007 —** Continued

Characteristic	Private industry [2,3,4]	Goods producing				Service providing							
		Total goods producing	Natural resources and mining[2,3]	Construction	Manufacturing	Total service providing	Trade, transportation and utilities[4]	Information	Financial activities	Professional and business services	Education and health services	Leisure and hospitality	Other services
Source of injury or illness:													
Chemicals and chemical products	17,340	6,040	840	1,290	3,910	11,300	3,450	350	760	1,430	2,460	2,270	580
Containers	136,750	28,460	1,960	5,770	20,720	108,290	70,480	1,660	2,780	7,130	9,570	15,020	1,660
Furniture and fixtures	46,220	8,300	150	2,930	5,220	37,920	15,610	370	2,220	3,540	9,270	5,490	1,430
Machinery	69,160	33,950	2,380	8,440	23,130	35,220	17,890	830	2,250	4,620	3,720	4,380	1,530
Parts and materials	116,570	67,440	3,080	29,880	34,480	49,120	33,220	1,030	1,150	5,280	2,190	1,830	4,430
Floors, walkways, ground surfaces[5]	230,550	58,400	4,870	29,320	24,210	172,150	65,660	4,840	9,550	19,420	42,760	23,390	6,520
Tools, instruments, and equipment	78,350	30,800	1,770	15,470	13,560	47,550	17,930	1,690	2,720	6,150	9,090	8,300	1,670
Vehicles	97,920	19,750	2,710	7,330	9,700	78,180	46,770	1,620	2,680	9,210	9,780	4,380	3,740
Person, injured or ill worker[5]	169,920	52,390	3,000	16,490	32,900	117,520	50,900	3,940	6,640	14,810	23,120	13,780	4,330
Worker motion or position[5]	165,110	51,130	2,920	15,910	32,300	113,980	49,150	3,850	6,320	14,380	22,540	13,480	4,250
Person, other than injured or ill worker	64,290	600	70	200	330	63,700	3,010	110	680	1,570	55,580	2,250	480
Health care patient	50,810	–	–	–	–	50,800	390	–	40	700	49,550	20	110
Event or exposure leading to injury or illness:													
Contact with objects and equipment	317,550	128,670	10,590	47,870	70,210	188,890	95,480	3,590	7,760	20,140	24,810	27,710	9,390
Struck by object	162,840	63,520	5,410	27,000	31,110	99,320	49,270	1,500	4,640	10,530	12,950	16,150	4,290
Struck against object	75,730	26,120	2,030	10,670	13,410	49,620	23,820	1,150	1,990	5,130	7,790	7,380	2,360
Caught in equipment or object	53,590	27,920	2,320	5,510	20,090	25,670	15,040	610	700	3,020	2,510	2,260	1,530
Fall to lower level	77,300	29,510	2,270	19,870	7,370	47,790	23,470	1,690	3,280	6,490	6,320	4,140	2,400
Fall on same level	166,560	34,060	2,690	12,570	18,790	132,500	47,640	3,200	6,910	13,360	36,890	20,020	4,490
Slip, trip, loss of balance without fall[5]	37,780	9,590	1,000	3,770	4,820	28,190	11,160	810	850	3,510	6,820	4,260	770
Overexertion	264,930	66,760	3,860	23,540	39,360	198,170	94,130	3,100	5,710	16,050	61,130	12,930	5,120
Overexertion in lifting	140,330	34,760	1,570	13,110	20,090	105,570	53,200	1,560	3,130	9,700	27,380	8,020	2,570
Repetitive motion	36,700	14,650	280	1,610	12,760	22,050	9,380	960	2,360	3,560	3,350	1,740	710
Exposure to harmful substances	52,950	16,000	1,120	5,040	9,840	36,940	10,270	1,150	1,560	4,450	7,560	9,870	2,090
Transportation accidents	53,320	10,540	1,460	5,310	3,770	42,780	22,610	1,260	1,920	6,360	6,500	2,110	2,020
Highway accident	33,360	5,480	740	3,470	1,270	27,880	13,490	960	1,650	4,530	5,140	790	1,330
Fires and explosions	1,870	920	120	320	480	950	590	–	20	90	90	110	–
Assaults and violent acts by person	16,840	550	110	210	240	16,280	2,730	120	620	860	10,740	1,110	120
Assaults by animal	7,280	1,210	750	260	200	6,070	1,650	110	200	2,830	520	240	530

[1] Days-away-from-work cases include those that resulted in days away from work, some of which also included job transfer or restriction.

[2] Excludes farms with fewer than 11 employees.

[3] Data for Mining (Sector 21 in the *North American Industry Classification System*-- United States, 2002) include establishments not governed by the Mine Safety and Health Administration rules and reporting, such as those in Oil and Gas Extraction and related support activities. Data for mining operators in coal, metal, and nonmetal mining are provided to BLS by the Mine Safety and Health Administration, U.S. Department of Labor. Independent mining contractors are excluded from the coal, metal, and nonmetal mining industries. These data do not reflect the changes the Occupational Safety and Health Administration made to its recordkeeping requirements effective January 1, 2002; therefore, estimates for these industries are not comparable to estimates in other industries.

[4] Data for employers in rail transportation are provided to BLS by the Federal Railroad Administration, U.S. Department of Transportation.

[5] **Selected estimates for this category were affected by the March 2009 revision, see note below.**

NOTE: Dash indicates data do not meet publication guidelines. Because of rounding and data exclusion of nonclassifiable responses, data may not sum to the totals.
This table was reissued in March 2009 to revise selected estimates within the Mining (NAICS 21) and Railroad Transportation (NAICS 482) industries, and in their respective higher level industry sectors. Characteristic categories affected by the revisions, that appear in this table, are footnoted.

SOURCE: Bureau of Labor Statistics, U.S. Department of Labor, Survey of Occupational Injuries and Illnesses in cooperation with participating State agencies

Source: Bureau of Labor Statistics (BLS)

APPENDIX B

Anthropometric Reference Data

Height in inches for females 20 years of age and older by race and ethnicity and age

Table 10. Height in inches for females 20 years of age and older by race and ethnicity and age, by mean, standard error of the mean, and selected percentiles: United States 2003–2006

Race and ethnicity and age	Number examined	Mean	Standard error	Percentile 5th	10th	15th	25th	50th	75th	85th	90th	95th
All race and ethnicity groups[1]				Inches								
20 years and over	4,857	63.8	0.06	59.3	60.3	61.0	62.1	63.8	65.6	66.6	67.2	68.2
20–29 years	1,061	64.3	0.12	59.9	60.9	61.6	62.5	64.2	66.1	66.9	67.5	68.0
30–39 years	842	64.3	0.13	60.0	60.8	61.5	62.5	64.2	66.0	67.1	67.7	68.6
40–49 years	784	64.2	0.12	59.9	60.6	61.4	62.4	64.2	66.0	66.9	67.7	68.5
50–59 years	604	63.9	0.13	59.3	60.4	61.2	62.2	63.8	65.7	66.4	67.1	67.9
60–69 years	691	63.7	0.13	59.8	60.5	61.1	62.1	63.7	65.3	66.1	66.9	67.5
70–79 years	463	62.7	0.13	58.6	59.4	60.1	61.0	62.6	64.4	65.2	65.9	66.7
80 years and over	412	61.4	0.15	57.5	58.3	58.8	59.7	61.3	62.9	63.9	64.7	65.4

Height in inches for males 20 years of age and older by race and ethnicity and age

Table 12. Height in inches for males 20 years of age and older by race and ethnicity and age, by mean, standard error of the mean, and selected percentiles: United States 2003–2006

Race and ethnicity and age	Number examined	Mean	Standard error	Percentile 5th	10th	15th	25th	50th	75th	85th	90th	95th
All race and ethnicity groups[1]				Inches								
20 years and over	4,482	69.4	0.07	64.4	65.6	66.3	67.4	69.4	71.5	72.6	73.2	74.3
20–29 years	808	69.9	0.13	64.7	65.8	66.6	67.8	70.0	72.0	73.0	73.5	74.8
30–39 years	742	69.4	0.13	64.1	65.3	66.1	67.5	69.5	71.5	72.7	73.4	74.7
40–49 years	769	69.7	0.11	65.2	66.2	66.8	67.9	69.7	71.6	72.7	73.3	74.0
50–59 years	591	69.5	0.15	65.0	65.8	66.5	67.5	69.5	71.5	72.7	73.4	74.4
60–69 years	668	69.0	0.11	64.2	65.4	66.1	67.1	69.0	71.1	71.9	72.7	73.7
70–79 years	555	68.4	0.16	63.8	64.6	65.5	66.4	68.5	70.3	71.0	72.0	73.1
80 years and over	349	67.2	0.14	62.7	63.6	64.3	65.5	67.2	68.9	70.0	70.5	71.3

Source Anthropometric reference data for children and adults: United States, 2003–2006

APPENDIX C

IRB Form

WICHITA STATE UNIVERSITY
COLLEGE OF ENGINEERING
Department of Industrial and Manufacturing Engineering

PURPOSE: You are invited to participate in a study evaluating the appropriateness of safe lifting weights identified by a lifting evaluation method (ACGIH TLV for Lifting) for people of different gender and of different heights.

PARTICIPANT SELECTION: You were selected as a possible participant in this study because you are in the age range of participants identified for this study (18 to 30 years of age) and likely in the height category of subjects identified for this study. We anticipate there will be between 18 and 30 participants in this study.

EXPLANATION OF PROCEDURES: The study will be performed in the Modular Multidisciplinary Bioengineering Lab in 108 Wallace Hall, and is expected to last 1 to 1.5 hours in duration. If you decide to participate, you will first be asked to provide information about any medical conditions that may increase your risk due to lifting boxes (e.g., prior injuries, surgeries to shoulder, back, legs). Affirmative answers will exclude you from participation. After consenting to participate and not being excluded due to medical reasons, small sensors will be placed on your skin using self-adhesive tape over your lower back muscles (lumbar erector spinae), your trapezius muscle near your neck and shoulder, your rectus abdominis muscle near your bellybutton, and your deltoid muscle of your upper arm near your shoulder. These sensors measure the electrical activity from your muscles during lifting. You will then be asked to perform two 5-second maximum muscle exertions for each of these muscles using the following postures:

- Lumbar erector spinae: Lying prone on a bench, subjects will extend their torso against manual resistance against the upper torso area.
- Rectus abdominis: Lying with the back on a bench, subjects attempt a sit-up motion against manual resistance with the spine flexed approximately 30 degrees.
- Deltoid: In a seated position with arms in approximately 90 degrees abduction, subjects attempt to move arms upward against manual resistance.
- Trapezius: Lying prone on a bench, subjects will extend their shoulder/upper arm against manual resistance.

Following the maximum muscle exertions, a back monitor (industrial lumbar motion monitor) will be placed on your back, which will measure the motion of your back (forward bending, twisting, side bending) as you lift boxes. The back monitor will be attached to a waist harness and a shoulder harness. You will then be asked to perform the lifting tasks as follows, lifting from the origin described below to a destination at waist level, and back to the origin again:

- Vertical Lifting Origin Height: Knee
  Horizontal locations: 45cm (7kg), 55cm (7kg), 65cm (2kg), 75cm (2kg)

- Vertical Lifting Origin Height: Elbow
  Horizontal locations: 45cm (9kg), 55cm (9kg), 65cm (5kg), 75cm (5kg)

You will lift a box four times (one lift every 15 seconds) per vertical and horizontal location combination, from the origin to destination, and back to the starting point again, for a total of 64 lifts. Following each of the vertical and horizontal location combinations, you will then be asked to rate your perception of 'heaviness' of the lifting scenario just completed.

DISCOMFORT/RISKS: Minimal discomfort should be experienced from the harness since it will be around your clothing, and there will likely be little to no discomfort wearing the back monitor as it weighs less than 2kg and will not restrict your motion. Slight redness or irritation may occur due to removal of the surface sensors, or due to pulling of hair, but should be very short in duration. during the lifting task due your limitations to move freely. You may also experience delayed muscle soreness to your shoulders or low back if you are not accustomed to lifting boxes. However, the weights selected to lift are considered low risk by the lifting assessment tool, and the muscle soreness should disappear in up to 48 hours.

BENEFITS: There will likely be no direct benefit to the human subjects who participate in this study. The benefits to scientific knowledge will include the assessment of the ACGIH TLV for Lifting with respect to the analysis of lifting tasks that include the destination of the lift, as well as if the safe weight limits identified by the Threshold Lifting Values are also identified as low risk by a statistical risk model that identifies risk for low back injury risk.

CONFIDENTIALITY: All information obtained from this study in which you can be identified will remain confidential and will be disclosed only with your permission.

COMPENSATION OR TREATMENT: Wichita State University does not provide medical treatment or other forms of reimbursement to persons injured as a result of or in connection with participation in research activities conducted by Wichita State University or its faculty, staff, or students. If you believe that you have been injured as a result of participating in the research covered by this consent form, you can contact the Office of Research Administration, Wichita State University, Wichita, KS 67260-0007, telephone (316) 978-3285.

REFUSAL/WITHDRAWAL: Participation in this study is entirely voluntary. Your decision whether or not to participate will not affect your future relations with Wichita State University. If you agree to participate in this study, you are free to withdraw from the study at any time without penalty.

CONTACT: If you have any questions about this research, you can contact me at: Muci Chali, mucich@hotmail.com or Michael J. Jorgensen, Ph.D., 120 Engineering Building, Wichita, KS, 67260-0035, michael.jorgensen@wichita.edu, (316) 978-5904. If you have questions pertaining to your rights as a research subject, or about research-related injury, you can contact the Office of Research Administration at Wichita State University, Wichita, KS 67260-0007, telephone (316) 978-3285.

You are under no obligation to participate in this study. Your signature indicates that you have read the information provided above and have voluntarily decided to participate.

You will be given a copy of this consent form to keep.

____ ____________________

Signature of Subject Date

____ ____________________

Witness Signature Date