THE PENNSYLVANIA STATE UNIVERSITY
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EFFECTS OF ADDED WEIGHT AND GIRTH ON STATIC STRENGTH

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ABSTRACT

The rise of obesity is a challenge our world is facing today. In the workplace the National Institute of Occupational Safety and Health (NIOSH) has outlined guidelines for the recommended weight a person should not exceed when lifting an item repeatedly throughout the work day (United States, 1994). One of the limitations of the 1991 lifting guidelines is that it does not account for a different body structure, such as obesity (Blosser, 2007). The purpose of this research is to compare the lifting capacities of the normal, overweight, and obese weight groups as well as determine if it is the added weight, added girth, or the added weight and girth that contributes to the change in lifting capacity.

During the experiment the lifting capacity, using the leg and then torso muscles, of the participants was measured. Next, the participants completed the maximum acceptable weight of lifts (MAWL), which determined the maximum amount they would be comfortable lifting every 15 seconds during an eight hour work day. Phase 2 of the experiment was completed by the normal weight category participants. They were asked to perform the lifts again but with a 19.7 pound weight vest on, a pregnant belly, and then with both on. The weight vest simulated added weight and the pregnant belly simulated added girth. These procedures follow the protocol developed by Lorna Cintron (2012).

The results of the experiment showed that in Phase 1, gender, height, and weight were used to predict the lifting capacity using the leg and torso muscles. The regression model for the leg muscles had an R-squared value of 49.5% and the torso muscles had an R-squared value of 57.1%. The MAWL model produced an R-squared value of 37.7%, using the gender and leg average, which is worse than the previous models due to the subjective nature of the test. Phase 2 found that the added weight and girth were not significant factors in the regression model for the leg average, which produced an R-squared value of 54.1%. In contrast, the regression model for the torso average found that the added weight, girth, gender, and height were significant with an R-squared value of 60.7%. It was then determined that the extra weight on the back impacted the individual's ability to lift with their torso muscles. This research and two other studies have looked at the impact of obesity on lifting capabilities, but more research needs to be completed to prevent individuals in the workplace from developing lower back pain or injuring themselves on the job or outside of work.

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I would also like to thank Lorna Cintron, a PhD Candidate in the Department of Industrial and Manufacturing Engineering. She originally designed the experiment and submitted the experiment for approval from the Institutional Review Board (IRB). Lorna oversaw the data collection from half the participants and trained myself and several research assistants on how to collect the data. Additionally she has helped with advertisement of the research study.

In addition, several undergraduate students have helped with the data collection and analysis. Alexis Bianco, Geoffrey Wolpert, Lindsay Beyers, and Katherine Dempster have all helped with the data collection. Alexis and Lindsay have also helped post flyers around campus for recruitment of participants.

Lastly, I would like to thank my parents for their unconditional love and support as I continued my education at Penn State to pursue my master's degree. They have taught me to pursue what I think is important to me, whether it was academics, extra-curricular activities, or music. Throughout my time at Penn State they have supported me even when it became difficult. They have inspired me to make a difference in the world and to follow my passions.

Chapter 1

Introduction

1.1 Background Information

The National Institute of Occupational Safety and Health (NIOSH) developed the NIOSH lifting guidelines to help prevent back injuries in repetitive lifting tasks. The recommended weight limit (RWL) equation was developed to define the maximum weight of a load that nearly all healthy workers could perform over a substantial period of time under certain conditions (United States, 1994). The lifting index (LI) is used to define a relative estimate of the level of physical stress associated with a particular manual lifting task and is defined by LI = L/RWL, where L is the load weight (United States, 1994). In addition, the RWL and LI equations can be used to identify specific job related problems, redesign and design manual lifting jobs, estimate the relative magnitude of physical stress for a job, and used to prioritize ergonomic redesign (United States, 1994). One limitation of the NIOSH lifting guidelines is how being obese or overweight affects the amount that should be lifted. This is the main topic of this thesis and was brought up at NIOSH as well (Blosser, 2007).

One of the problems the world is facing today is the rise of obesity. The World Health Organization (WHO) reported that in 2008 1.5 billion adults, 20 and older, were overweight and of these, 500 million were obese (Obesity, 2011). Obesity is defined as having a body mass index (BMI) of over 30 and overweight as over 25 (Obesity, 2011). Figure **1-1** below shows the trend of overweight, obese, and extremely obese in the United States (United States, 2010). From Figure **1-1** it can be seen that the percentages of obesity and extreme obesity have leveled off in recent years and have not been increasing as rapidly, which was also concluded in the analysis by Flegal et al. in 2010. Figure **1-2** shows the most recent prevalence in United States adults and shows the percent of obesity separated by age group and gender from 2009-2010 (Ogden et al., 2012). The prevalence of obesity can be found in the workplace and a main concern is the cost associated with obesity.

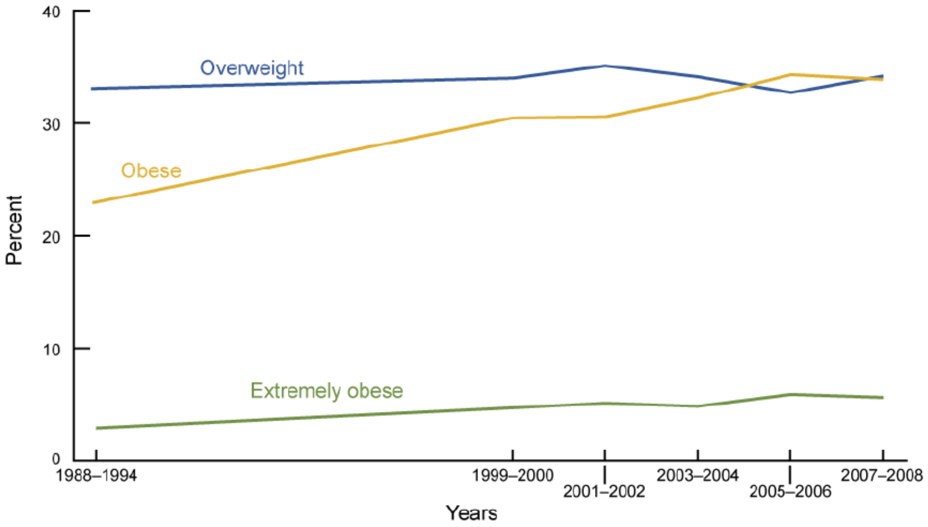


Figure **1-1**: Trends in overweight, obesity, and extreme obesity among adults aged 20 years and over: United States, 1988-2008 (adopted from United States, 2010)

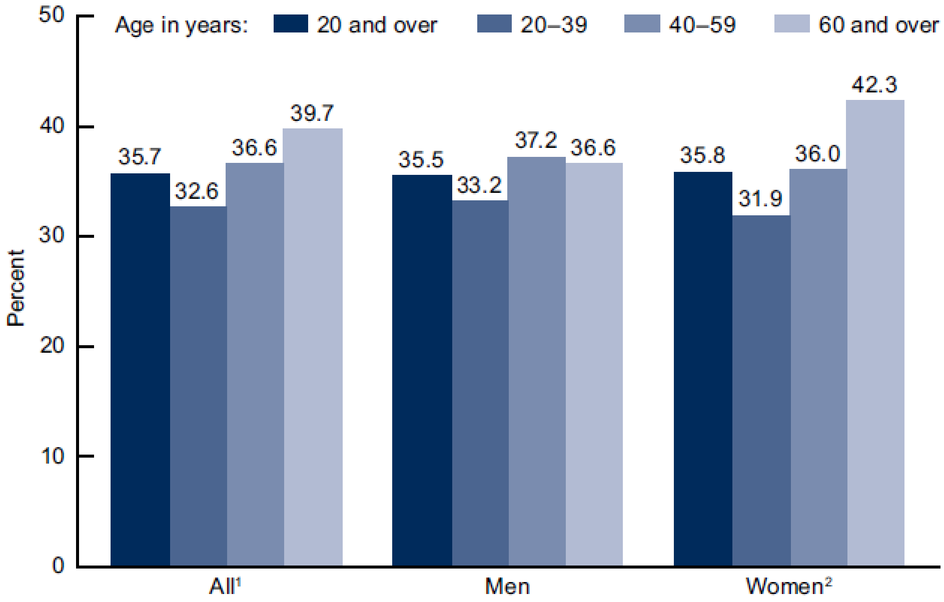


Figure **1-2**: Prevalence of obesity among adults aged 20 and over, by sex and age: United States, 2009-2010 (adopted from Ogden et al., 2012)

Companies are concerned about the prevalence of obesity among their workers because of the cost. If they can reduce this cost, they can reinvest the money in other parts of the company. Eric A. Finkelstein et al. looked at the medical costs of all workers, absenteeism, which is the amount of work missed due to health problems, and presenteeism, which is when health problems affect productivity (2010). For men, all the costs ranged from $9507, for the normal category, to $15,561, for the obesity III category (Finkelstein et al., 2010). In addition, for women, estimates ranged from $10,241 for normal weight to $16,969 for grade III obesity (Finkelstein et al., 2010). Presenteeism represented the highest cost and represented 56% for men and 68% for women of the total cost (Finkelstein et al., 2010). The total cost of obesity of US full-time employees was estimated to be $73.1 billion (Finkelstein et al., 2010). Paul Schulte et al. performed a literature review to see if work and work conditions influenced obesity and body weight (2007). They discovered that not many studies showed that obesity was a risk factor in the development of many work-related illnesses and injuries (Schulte et al., 2007). They called for an intervention on the employer's part to reduce obesity and overweightness in the workplace (Schulte et al., 2007). Addressing obesity in the workplace will improve the employee's health and decrease the company's medical expenses (Schulte et al., 2007). Another source of costs is the number of injuries that occur at the workplace.

Companies want to keep the injury rate low; therefore, it is important to if there is a relationship between obesity and injury rate. Huiyun Xiang et al. performed a survey to see if there was a higher risk of non-fatal injuries with obesity (2005). One adult over 18 years of age was selected from each household and asked if they had experienced an injury in the last 12 months that resulted them seeking medical attention or restrict usual activities temporarily (Xiang et al., 2005). The participants were classified into the categories, underweight, normal weight, overweight, obesity I, and obesity II (Xiang et al., 2005). The percentages of injured overweight individuals were similar to the normal weight group, while the obese participants had a 10%

higher percentage of injured participants than the normal weight group (Xiang et al., 2005). Obese individuals were found to have higher percentages of injuries caused by acute overexertion of the body and the univariate logistic model showed that the participants in the obesity II category had a higher odds ratio of injuries compared to the non-obese group (Xiang et al., 2005). It is important to recognize the risks associated with certain tasks in the workplace.

This research will look at the three different weight categories, normal, overweight, and obese, to see if they have an impact on lifting capability. Not many studies have addressed this link and the ones that have will be discussed further in the literature review. To determine what is contributing to the impact on lifting capability, added weight and girth will be simulated by the participants in the normal weight category. This research, along with additional research in this topic, will then be used by NIOSH to determine if new lifting guidelines need to be written and help companies address obesity in the workplace.

1.2 Organization of this Research

Chapter 2 will present an extensive literature review of past research that was used when creating the NIOSH lifting guidelines, how obesity is classified, the relationship between obesity and non-fatal injuries, the relationship between obesity and lifting, and repetitive lifting research. Chapter 3 will summarize the experiment problem statement, as well as the hypotheses and the experiment protocol. Chapter 4 will present the results of the experiment along with an analysis. Chapter 5 will relate this research back to the literature review and summarize key conclusions. In addition, it will present suggestions for areas of further research.

Chapter 2

Literature Review

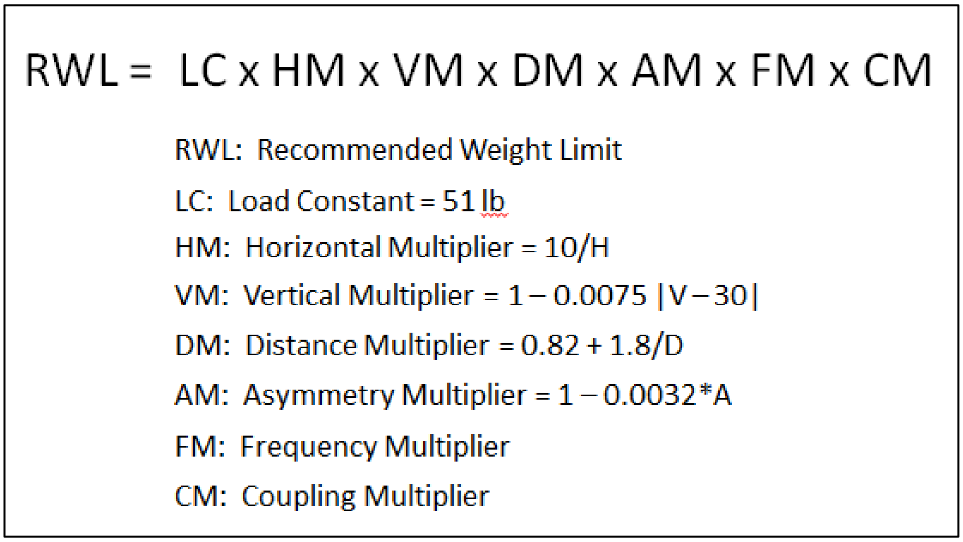
2.1 Revised NIOSH Lifting Guidelines

The NIOSH lifting guidelines were first established in 1981 to assist safety and health practitioners compute a weight limit for manual lifting in order to decrease lifting-related low back pain among workers (Waters et al., 1993). In 1991, the equation was updated to reflect new findings, to incorporate asymmetrical lifting tasks and tasks with less than optimal hand-container couplings, and to evaluate a larger range of work durations and lifting frequencies (Waters et al., 1993). Ad hoc NIOSH committees of experts reviewed current lifting literature, defined criteria that would determine lifting capacity, and developed a lifting equation (Waters et al., 1993). The criteria that were chosen to establish the lifting equation was based on a scientifically supported, quantitative relationship between the criteria and the actual risk of lifting-related musculoskeletal injury (Waters et al., 1993). Since such criteria does not exist, secondary measures were used to satisfy biomechanical, physiological, and psychophysical criteria.

For the biomechanical criterion, a review of previous studies determined that the disc between the L5 and S1 vertebrae on the spine has the potential to incur the greatest moment in lifting (Waters et al., 1993). The disc compressive force was chosen as the critical stress vector underlying this criterion and the committee decided the maximum compressive force that should be experienced by the L5/S1 vertebrae is 3.4 kN (Waters et al., 1993). Next, the physiological criterion was selected because repetitive lifting tasks were determined to require multiple groups of muscles to move both the load and the body, therefore needing sufficient oxygen for contraction (Waters et al., 1993). It was recognized that an excess use of a worker's normal energy capacities would cause a premature decrease in strength and increase the likelihood of injury (Waters et al., 1993). 9.5 kcal/min was determined to the baseline measure of maximum aerobic lifting capacity (Waters et al., 1993). 70% of the baseline was determined for lifts that were above 30 inches (Waters et al., 1993). For tasks lasting an hour, 50% of the baseline was used, for tasks lasting 1-2 hours, 40% was used, and for tasks last 2-8 hours, 33% was used (Waters et al., 1993). Lastly, the psychophysical criterion was determined by using maximum-acceptable-weight-of-lift, which is the amount of weight a person chooses to lift under given conditions for a defined period (Waters et al., 1993). This determines what a person can do repeatedly for an extended period without excessive fatigue which may lead to lifting-related low back pain (Waters et al., 1993). The committee selected the criteria that would not exceed the acceptable lifting capacity of about 99% of male workers and 75% of female workers, which was estimated to be 90% of the working population (Waters et al., 1993). The committee used these criteria to develop the recommended weight limit equation to help decrease back injuries.

There are some additional limitations of the equation and the criteria used to develop it. First, the psychophysical data may reveal more about a worker's tolerance to stress than of impending low back pain (Waters et al., 1993). A review of literature showed that this approach overestimates the capacity for lifting more than six lifts/min and lifts lasting more than an hour (Waters et al., 1993). The physiological criterion addresses the level of whole body fatigue, but this may be independent of the cumulative effects of repetitive lifting (Waters et al., 1993). The multiplicative nature of the equation will provide a better way to protect workers than each of the individual criterion (Waters et al., 1993).

The recommended weight limit equation is defined by the multipliers in Figure **2-1** (United States, 1994). Figure **2-2** defines the H and V variables and Figure **2-3** defines the A variable, which is amount of twisting that occurs during the lift (United States, 1994). Table **2-1** defines the frequency multiplier, which is based on the work duration and vertical distance of the lift (United States, 1994). To determine the coupling multiplier, the decision tree in Figure **2-4** is used to determine the coupling type and then Table **2-2** is used, which also incorporates the vertical distance of the lift (United States, 1994). The limitations of this equation, is that it is limited to strict lifting and lowering, lifts that occur during an 8 hour work day or less, two handed lifting, lifting while standing, lifting slower than 30 inches/second, lifts where the coefficient of static friction is at least 0.4, and to tasks that have the same level of risk for low back injuries (United States, 2012). A comprehensive literature review was completed in order to define the lifting guidelines in 1988 and then again in 1991; therefore, more research on obesity and lifting needs to be completed to help NIOSH further revise the guidelines. In the following section, the classification of obesity will be discussed.



$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM$$

RWL: Recommended Weight Limit

LC: Load Constant = 51 lb

HM: Horizontal Multiplier = 10/H

VM: Vertical Multiplier = $1 - 0.0075\,|V - 30|$

DM: Distance Multiplier = $0.82 + 1.8/D$

AM: Asymmetry Multiplier = $1 - 0.0032*A$

FM: Frequency Multiplier

CM: Coupling Multiplier

Figure **2-1**: Recommended Weight Limit Equation (adopted from United States, 1994)

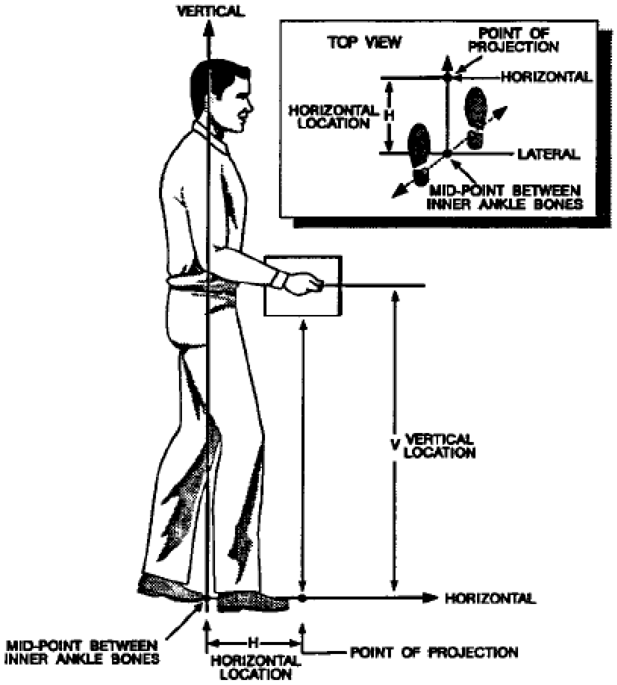


Figure **2-2**: Graphic Representation of Hand Location (adopted from United States, 1994)

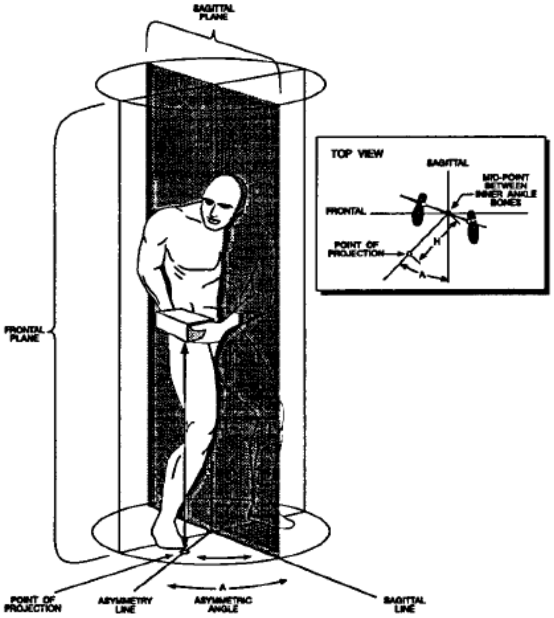
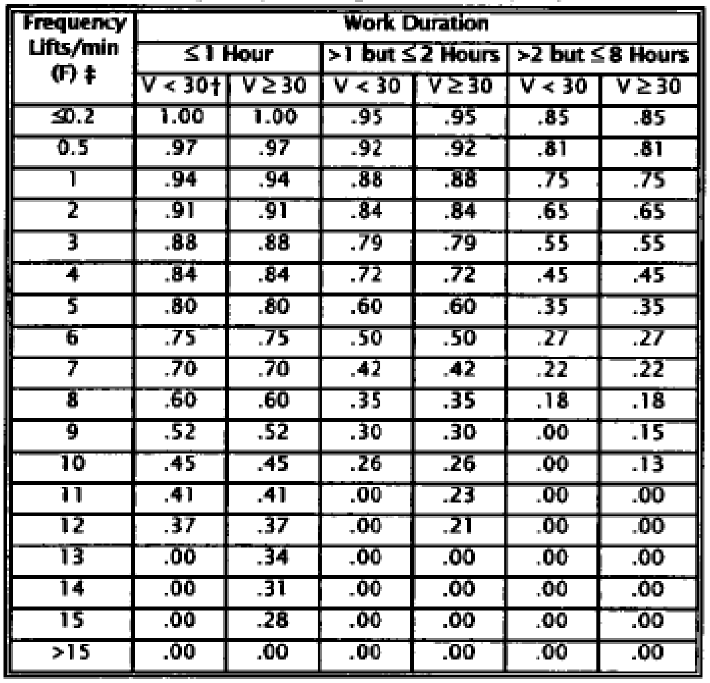


Figure **2-3**: Graphic Representation of Angle of Asymmetry (adopted from United States, 1994)

Table **2-1**: Frequency Multiplier Table (adopted from United States, 1994)



Frequency Lifts/min (F) ‡	Work Duration					
	≤ 1 Hour		>1 but ≤ 2 Hours		>2 but ≤ 8 Hours	
	V < 30†	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

†Values of V are in inches. ‡For lifting less frequently than once per 5 minutes, set F = .2 lifts/minute.

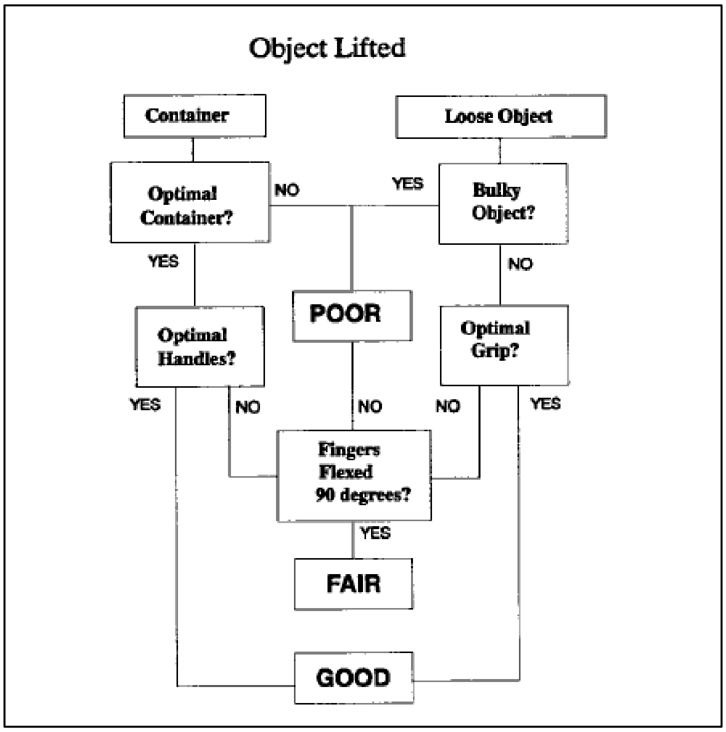
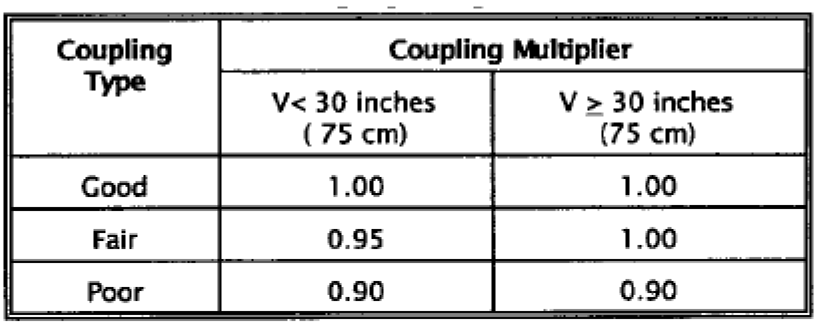


Figure **2-4**: Decision Tree for Coupling Quality (adopted from United States, 1994)

Table **2-2**: Coupling Multiplier (adopted from United States, 1994)



Coupling Type	Coupling Multiplier	
	V< 30 inches (75 cm)	V ≥ 30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

2.2 Classification of Obesity

Before incorporating obesity or body weight into the NIOSH lifting guidelines, the different classifications of obesity must be thoroughly researched. The National Institute of Health released guidelines on the risk factors of obesity and how to define obesity (United States, 1998). They stated that though there are many different ways to measure obesity and body fat, BMI is used since it is a readily available procedure that can provide an acceptable approximation of total body fat for the majority of patients (United States, 1998). Body mass index is calculated by dividing the weight, in kilograms, by the height squared, in squared meters (United States, 1998). Waist circumference was another measure of body fat recommended, especially if assessing a patient's abdominal fat content during weight loss treatment (United States, 1998). This committee did observe that no published studies that compare the effectiveness of different measures for evaluating body fat (United States, 1998). Since then at least one study has been conducted. This study conducted by David Frankenfield et al. looked to see the limits of body mass index to detect obesity and predict body composition (2001). The participant's body mass index was calculated and their fat free mass was calculated using resistance (Frankenfield et al., 2001). The equations were defined as follows (Frankenfield et al., 2001):

$$male: fat - free\ mass\ (kg)$$

$$= 22.668 + 0.00132\ (height^2) - 0.4394(resistance) + 0.3052(body\ mass) - 0.1676(age)$$

$$female: fat - free\ mass(kg)$$

$$= 14.594 + 0.00108(height^2) - 0.0209(resistance) + 0.23199(body\ mass) - 0.06777(age)$$

Body fat was determined as the difference between total body mass and impedance-derived fat-free mass and the percentage of body fat calculated as the ratio of body fat to total body mass (Frankenfield et al., 2001). Obesity was defined as BMI above 30 kg/m^2 or body fat greater than or equal to 25% of body weight in men and greater than or equal to 30% in women (Frankenfield et al., 2001). The results of the study showed that 30% of men and 46% of women who had a BMI below 30 kg/m^2 qualified as obese by the percentage of body fat (Frankenfield et al., 2001). This led to the conclusion that BMI was not an accurate way to classify obesity for participants below 30 kg/m^2 (Frankenfield et al., 2001). The regression models showed that to predict body fat from BMI resulted in a quadratic equation for men with an R-squared value of 0.886 and for women an R-squared value of 0.942 (Frankenfield et al., 2001). Also a regression model was created for using BMI to predict body fat/height^2, which produced results that a linear equation for men had an R-squared value of 0.992 and for women an R-squared value of 0.997 (Frankenfield et al., 2001). These equations show that it is better to use BMI to predict body fat/height^2 than percentage body fat (Frankenfield et al., 2001). More research needs to be completed to determine the best way to define obesity. The next section will expand on obesity and look at its relationship to non-fatal injuries.

2.3 The Relationship between Obesity and Non-Fatal Injuries

The NIOSH lifting guidelines were developed as a result of a high amount of back injuries, in the same manner the NIOSH lifting guidelines should be revised due to the research on the relationship between obesity and non-fatal injuries and diseases. Obesity has been associated with a higher risk of developing some illnesses and diseases. Ingrid Heuch et al. looked at the impact of body mass index on the prevalence of low back pain through a large cross-sectional population-based study among adults in Norway asking if the participant had suffered from pain or stiffness in muscles or joints at least 3 months continuously in the last year (2010). The results of the study showed that the prevalence of chronic low back pain was higher among individuals with an increased body mass index and was stronger in women (Heuch et al., 2010). Having back pain or any pain in the rest of the body can indicate that a person is putting too much strain on a certain areas, which could lead to injury.

Keshia Pollack et al. researched the connection between body mass index and acute traumatic workplace injury in hourly manufacturing employees (Pollack et al., 2007). The participants were workers were on payroll during the calendar year 2002, between the ages of 18 and 67, and worked at either a plant in the production of aluminum or at a plant fabricating aluminum products (Pollack et al., 2007). The outcome was the occurrence of any traumatic work-related injury between January 1, 2002, and December 31, 2004 (Pollack et al., 2007). The participants were divided into six categories by BMI and additional variables included age, race/ethnicity, highest level of education, smoking status, time since hire in years, time in current jog in months, and physical demand of job was classified (Pollack et al., 2007). The results showed that the obese participants had a higher amount of acute traumatic workplace injuries than their normal counterparts and also had a higher odds ratio than the normal group (Pollack et al., 2007). One point of concern with this study was that there was a higher presence of overweight and obese participants than the current US population (Pollack et al., 2007). In addition, Harry Shuford and Tanya Restrepo performed several case studies to compare the medical costs of non-obese people with obese people (Shuford and Restrepo, 2010). This study concluded that obese patients have a greater risk that injuries they sustain will cause permanent disabilities (Shuford and Restrepo, 2010). Case studies that were completed showed that for the same injury type, the range of medical treatments and costs, as well as duration, were usually greater for obese patients than non-obese (Shuford and Restrepo, 2010). Several studies have provided the motivation behind this research, which is that obesity leads to a higher risk of injuries and developing some illnesses and diseases. The next section will look at the current research of the relationship between obesity and lifting.

2.4 The Relationship Between Obesity and Lifting

Very little research has been done to discover the effects of obesity on lifting. The effects of obesity on lifting performance were studied by Xu Xu, Gary A. Mirka, and Simon M. Hsiang. In this experiment, a group of 12 men, half with BMI less than 25 kg/m^2 and the other half with BMI greater than 30 kg/m^2 had a lift a box from two different starting positions with two different loads with lifts performed every 10 seconds (Xu et al., 2008). The Lumbar Motion Monitor was used to capture trunk kinematics during the lifting tasks and the angular velocities and accelerations were calculated (Xu et al., 2008). The results of this experiment showed that BMI had a strong effect on rotational velocity, rotational acceleration, sagittal velocity, and sagittal acceleration (Xu et al., 2008). The results showed that the obese participants had higher measures for the dynamics of lifting motion than the normal participants (Xu et al., 2008). This paper concluded that a more appropriate measure of obesity was needed since the obese participants demonstrated greater muscle strength (Xu et al., 2008). Obesity is measured based on height and weight and does not take into account whether a person has a lot of body fat or muscle.

In another study, Devender Singh, Woojin Park, and Martin S. Levy performed an experiment to see if obesity reduced the maximum acceptable weights of lift (2009). They divided the participants into three levels of obesity with 10 males and 10 females in each (Singh et al., 2009). The categories were divided by BMI where non-obese was from 18.5 kg/m2 to 24.9 kg/m^2, moderately obese was from 35 kg/m2<BMI<39.9 kg/m^2, and extremely obese was over 40 kg/m2 (Singh et al., 2009). The main hypothesis was to test that obesity reduces the maximum acceptable weights of lift (MAWL) (Singh et al., 2009). Other effects that were observed were gender, lifting frequency, lifting height and their interactions on MAWL (Singh et al., 2009). Gender, lifting height, and lifting frequency were found to be statistically significant while obesity was not (Singh et al., 2009). The two-way interactions of obesity and lifting frequency, gender and lifting frequency and height and lifting frequency were found to be significant (Singh et al., 2009). The results of the experiment disproved the hypothesis as the obesity groups were not found to be statistically significant (Singh et al., 2009). Other significant conclusions showed that the floor to knuckle lifting position had the highest results for MAWL (Singh et al., 2009). Obesity was found to increase MAWL by small amounts for lifting frequencies (Singh et al., 2009). The obese participants appear to have grown accustomed to the additional weight and have developed muscles in places that normal participants did not have (Singh et al., 2009). One concern of the study is that there needs to be more research on the ability of people to perceive their lifting stress (Singh et al., 2009).

Though this study did not look at lifting, a study performed by Luca Vismara et al. looked at the effect of obesity and low back pain on spinal mobility in females (2010). A total of 37 volunteers divided in three groups, 13 obese without low back pain (group O), 13 obese with non-specific chronic LBP (group cLBP), and 11 healthy women no history of musculoskeletal complaints (group C) (Vismara et al., 2010). Reflective markers were placed on the participants back in the manner shown in Figure **2-5** and data was collected using a 6 camera optoelectronic motion analysis system (Vismara et al., 2010). The angles measured can be seen in Figure **2-6** and the results of the forward flexion movement can be seen in Table **2-3** where START is the initial standing position, MAX is the maximum forward flexion, and ROM is the range of motion (Vismara et al., 2010). Between the obese and normal groups, there was significant difference for forward trunk inclination (αFTI) and anterior pelvic tilt (α1) for the standing position (Vismara et al., 2010). For the maximum forward flexion, the obese and normal groups had significant difference for angle related to lordosis (αL), angle related to kyphosis (αK), and thoracic movement (α3) (Vismara et al., 2010). In addition, for the range of motion, there was significant difference between the normal and obese groups for the forward trunk inclination (αFTI), angle related to kyphosis (αK), and thoracic movement (α3) (Vismara et al., 2010). This research showed that the obese participants had statistically significant differences from the normal group in regards to initial standing position, maximum forward flexion, and range of motion (Vismara et al., 2010). The past research showed that the obese participants were capable of lifting more than the normal participants and that obesity affected the range of motion. In addition, the next section will discuss a research experiement in repetitive lifting.

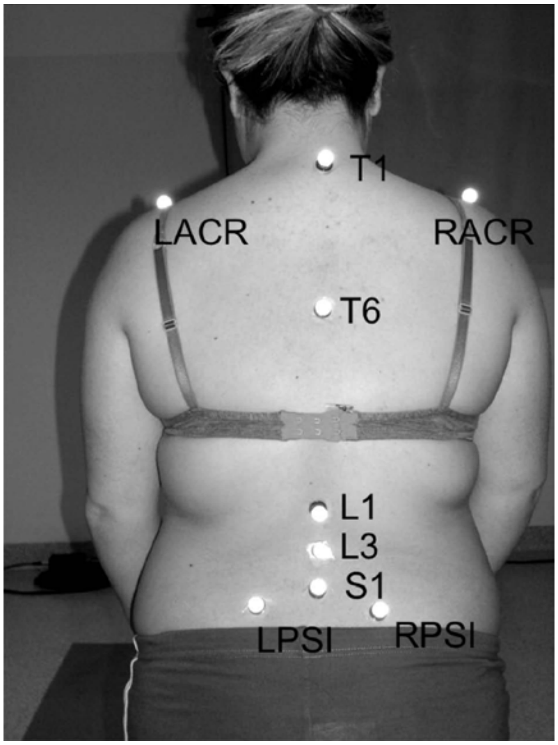


Figure **2-5**: Marker Placements for Motion Analysis System (adopted from Vismara et al., 2010)

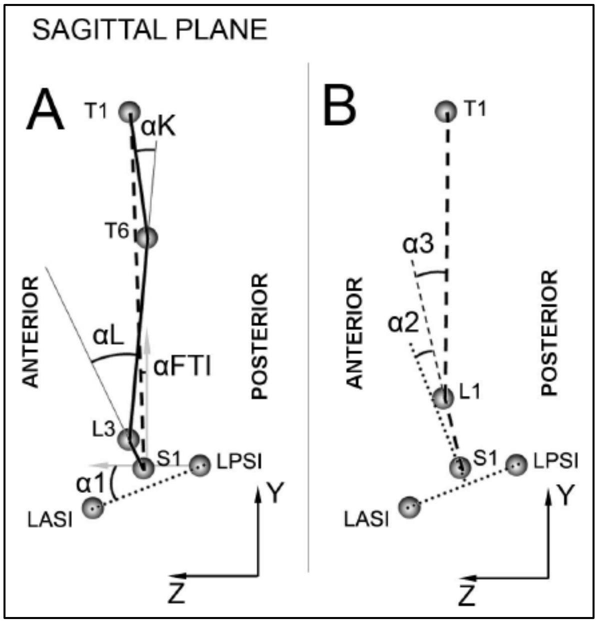
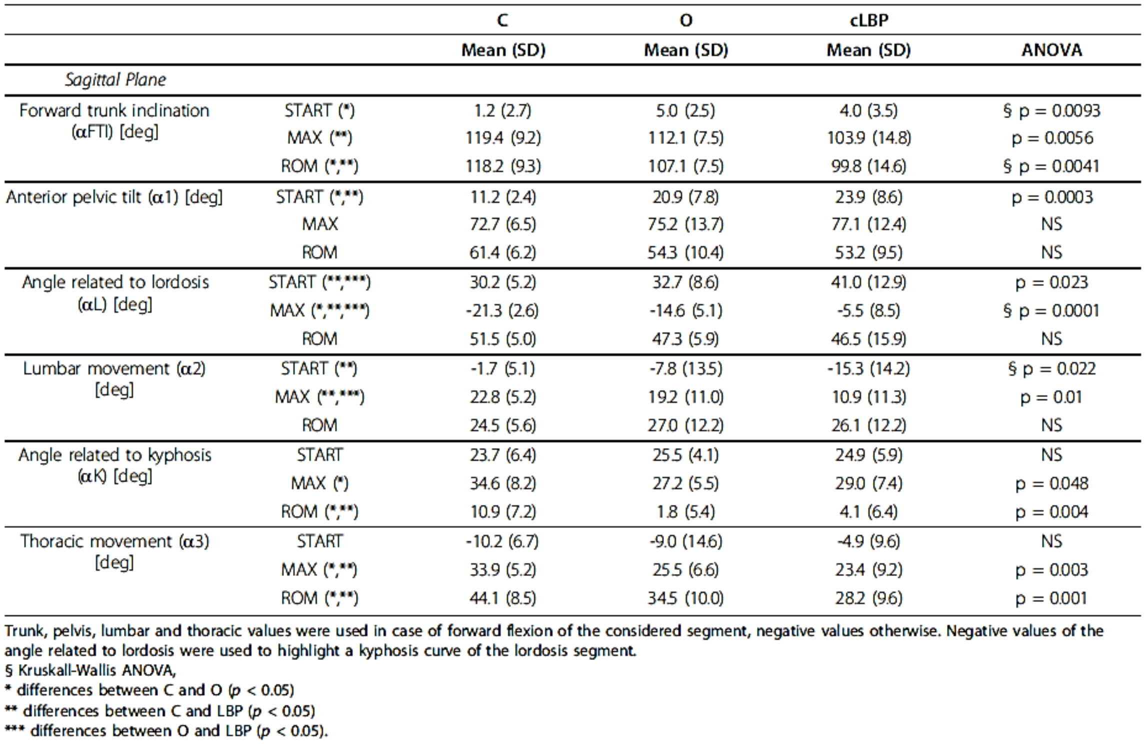


Figure **2-6**: Angles Measured in Study (adopted from Vismara et al., 2010)

Table **2-3**: Main Results About the Forward Flexion Movement (adopted from Vismara et al., 2010)



		C	O	cLBP	
		Mean (SD)	**Mean (SD)**	**Mean (SD)**	**ANOVA**
Sagittal Plane					
Forward trunk inclination (αFTI) [deg]	START (*)	1.2 (2.7)	5.0 (2.5)	4.0 (3.5)	§ p = 0.0093
	MAX (**)	119.4 (9.2)	112.1 (7.5)	103.9 (14.8)	p = 0.0056
	ROM (*,**)	118.2 (9.3)	107.1 (7.5)	99.8 (14.6)	§ p = 0.0041
Anterior pelvic tilt (α1) [deg]	START (*,**)	11.2 (2.4)	20.9 (7.8)	23.9 (8.6)	p = 0.0003
	MAX	72.7 (6.5)	75.2 (13.7)	77.1 (12.4)	NS
	ROM	61.4 (6.2)	54.3 (10.4)	53.2 (9.5)	NS
Angle related to lordosis (αL) [deg]	START (**,***)	30.2 (5.2)	32.7 (8.6)	41.0 (12.9)	p = 0.023
	MAX (*,**,***)	-21.3 (2.6)	-14.6 (5.1)	-5.5 (8.5)	§ p = 0.0001
	ROM	51.5 (5.0)	47.3 (5.9)	46.5 (15.9)	NS
Lumbar movement (α2) [deg]	START (**)	-1.7 (5.1)	-7.8 (13.5)	-15.3 (14.2)	§ p = 0.022
	MAX (**,***)	22.8 (5.2)	19.2 (11.0)	10.9 (11.3)	p = 0.01
	ROM	24.5 (5.6)	27.0 (12.2)	26.1 (12.2)	NS
Angle related to kyphosis (αK) [deg]	START	23.7 (6.4)	25.5 (4.1)	24.9 (5.9)	NS
	MAX (*)	34.6 (8.2)	27.2 (5.5)	29.0 (7.4)	p = 0.048
	ROM (*,**)	10.9 (7.2)	1.8 (5.4)	4.1 (6.4)	p = 0.004
Thoracic movement (α3) [deg]	START	-10.2 (6.7)	-9.0 (14.6)	-4.9 (9.6)	NS
	MAX (*,**)	33.9 (5.2)	25.5 (6.6)	23.4 (9.2)	p = 0.003
	ROM (*,**)	44.1 (8.5)	34.5 (10.0)	28.2 (9.6)	p = 0.001

Trunk, pelvis, lumbar and thoracic values were used in case of forward flexion of the considered segment, negative values otherwise. Negative values of the angle related to lordosis were used to highlight a kyphosis curve of the lordosis segment.
§ Kruskall-Wallis ANOVA,
* differences between C and O ($p < 0.05$)
** differences between C and LBP ($p < 0.05$)
*** differences between O and LBP ($p < 0.05$).

2.5 Repetitive Lifting Research

Since the NIOSH lifting guidelines were updated in 1991, additional research has been done related to repetitive lifting. A study performed by K.P. Granata with other authors (1999) looked at the variation in spinal load and trunk dynamics during repetitive lifting exertions. The male subjects were either college students or experienced manual materials handler warehouse selectors (Granata, 1999). The subject lifted a weighted box, of two different weights, to two different levels of task asymmetry at two different speeds (Granata, 1999). Even though the lifts were performed under identical and repeated lifting conditions, the results showed that lifting kinetics, kinematics, and spinal load demonstrated significant variability (Granata, 1999). This results in a large fraction of lifts that may exceed the recommended levels even though they are below the tolerance limits (Granata, 1999). This research showed that more research needs to be completed to understand what is the safe lifting amount.

Chapter 3

Experimental Design

3.1 Problem Statement and Objectives

With the rise of the number of people who are obese or overweight, it is important to see if this increased weight impacts the amount that can be safely lifted to avoid a possible future injury. At the time there is not much research in this area; therefore, it is important to determine if increased weight and girth impacts lifting capabilities and verify other research in this area. The NIOSH lifting guidelines were created assuming that there is no difference is a person's lifting ability based on their height and body weight. The lifting guidelines define the recommended weight limit based on how far the object to be lifted is from the lifter's center of gravity. A person, who is obese, has additional girth on their waist and this increased distance of the object from his or her body may affect his or her ability to lift. In addition, an obese person has additional weight that he or she has to lift when lifting the object. The experiment performed for this research strives to gain better understanding of the effects of the additional girth and weight.

The first null hypothesis that this research addresses is that there is no difference in strength based on the weight category of the participant. If this hypothesis is rejected, then the second null hypothesis consists of two parts. First, there is no difference in strength with the presence of additional weight. Second, there is no difference in strength with the presence of additional girth. The results of this research will help understand what impacts a person's ability to lift.

The first hypothesis was tested by having participants from all three weight categories, normal, overweight, and obese, demonstrate their lifting capabilities using their leg and torso muscles and determine their maximum acceptable weight limit (MAWL) for a repetitive lift every 15 seconds during an eight hour workday. The second hypothesis was tested by having the participants demonstrate their lifting capabilities with added girth, added weight, or both the added girth and weight to see what was causing the difference in lifting capacity. In addition, the participants of the study would have an opportunity to learn the proper way of lifting heavy objects. The results of this experiment will be analyzed and suggestions for future research will be discussed.

3.2 Experiment Protocol

The participants recruited for this research study were walked through the following protocol, which was developed by Lorna Cintron (2012). First, they signed a consent form stating what they would be doing during the study and filled out a medical questionnaire to make sure they qualified for the research study. The participants were required to be healthy and not be suffering from any musculoskeletal conditions or pain in the following body parts: neck, back, upper extremities, and heart. In addition, the participants were required to be between the ages of 20 and 34.

After the completion of the forms, the participant’s measurements were taken. First, each participant was asked their gender and age. Then, the height was taken by having the participant stand with their back against the wall, marking the wall with a marker, and using a tape measure to measure the height. Next, the height, age, and gender were entered into The Weight Watchers® WW78 by CONAIR Body Fat Analysis bathroom scale, which output the weight, body fat percent, and body mass index (BMI) of the participant. The scale uses bioelectrical impedance to estimate body fat. The BMI of the participant helped classify the participant in the three different weight groups, from 18.5 to 24.9 were normal, 25 to 29.9 were overweight, and above 30 was obese. In addition, the waist circumference was measured using a measuring tape. Lastly, the body fat was measured with a skinfold caliper, measured in millimeters in four separate places, the back below the shoulder blade, the lower abdominal area, bicep, and triceps. This number was converted based on the participant's gender and age using Table **3-1** below. All the data collected was entered in a Microsoft Excel spreadsheet, which only the researcher and research assistants had access to. This data can be seen in Appendix A in Table **A-1**. With this last measurement, the participant began the completion of the study.

Table **3-1**: Skin Caliper Conversion Tables

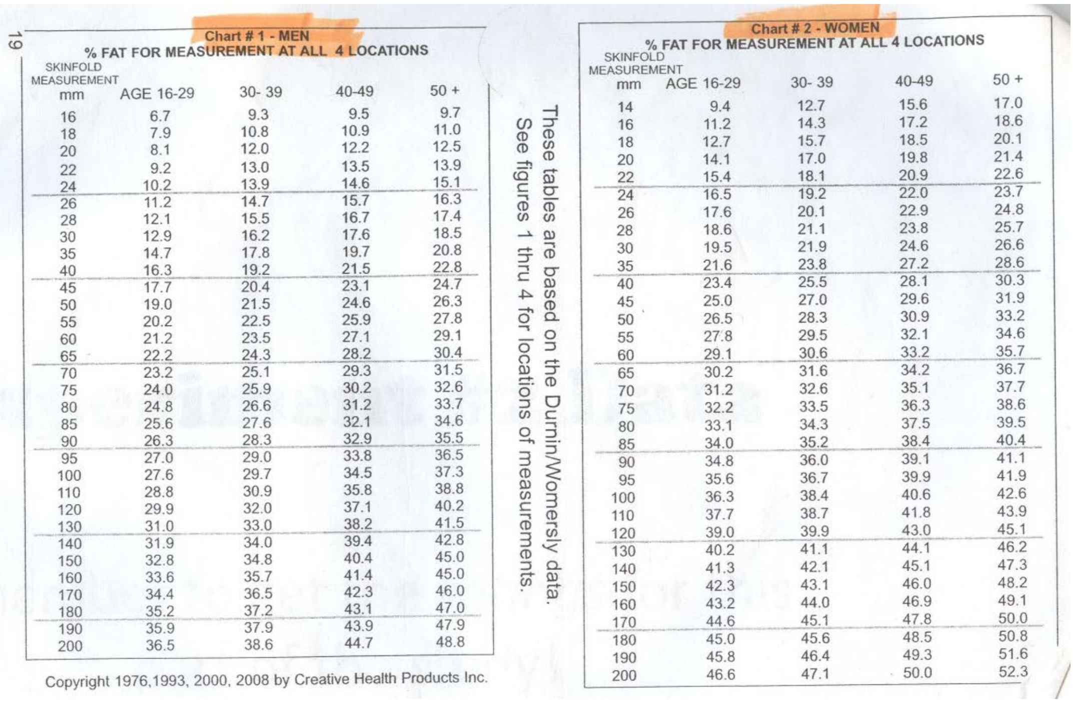


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Chart # 1 - MEN

% FAT FOR MEASUREMENT AT ALL 4 LOCATIONS

SKINFOLD MEASUREMENT mm	AGE 16-29	30- 39	40-49	50 +
16	6.7	9.3	9.5	9.7
18	7.9	10.8	10.9	11.0
20	8.1	12.0	12.2	12.5
22	9.2	13.0	13.5	13.9
24	10.2	13.9	14.6	15.1
26	11.2	14.7	15.7	16.3
28	12.1	15.5	16.7	17.4
30	12.9	16.2	17.6	18.5
35	14.7	17.8	19.7	20.8
40	16.3	19.2	21.5	22.8
45	17.7	20.4	23.1	24.7
50	19.0	21.5	24.6	26.3
55	20.2	22.5	25.9	27.8
60	21.2	23.5	27.1	29.1
65	22.2	24.3	28.2	30.4
70	23.2	25.1	29.3	31.5
75	24.0	25.9	30.2	32.6
80	24.8	26.6	31.2	33.7
85	25.6	27.6	32.1	34.6
90	26.3	28.3	32.9	35.5
95	27.0	29.0	33.8	36.5
100	27.6	29.7	34.5	37.3
110	28.8	30.9	35.8	38.8
120	29.9	32.0	37.1	40.2
130	31.0	33.0	38.2	41.5
140	31.9	34.0	39.4	42.8
150	32.8	34.8	40.4	45.0
160	33.6	35.7	41.4	45.0
170	34.4	36.5	42.3	46.0
180	35.2	37.2	43.1	47.0
190	35.9	37.9	43.9	47.9
200	36.5	38.6	44.7	48.8

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These tables are based on the Durnin/Womersly data.
See figures 1 thru 4 for locations of measurements.

Chart # 2 - WOMEN

% FAT FOR MEASUREMENT AT ALL 4 LOCATIONS

SKINFOLD MEASUREMENT mm	AGE 16-29	30- 39	40-49	50 +
14	9.4	12.7	15.6	17.0
16	11.2	14.3	17.2	18.6
18	12.7	15.7	18.5	20.1
20	14.1	17.0	19.8	21.4
22	15.4	18.1	20.9	22.6
24	16.5	19.2	22.0	23.7
26	17.6	20.1	22.9	24.8
28	18.6	21.1	23.8	25.7
30	19.5	21.9	24.6	26.6
35	21.6	23.8	27.2	28.6
40	23.4	25.5	28.1	30.3
45	25.0	27.0	29.6	31.9
50	26.5	28.3	30.9	33.2
55	27.8	29.5	32.1	34.6
60	29.1	30.6	33.2	35.7
65	30.2	31.6	34.2	36.7
70	31.2	32.6	35.1	37.7
75	32.2	33.5	36.3	38.6
80	33.1	34.3	37.5	39.5
85	34.0	35.2	38.4	40.4
90	34.8	36.0	39.1	41.1
95	35.6	36.7	39.9	41.9
100	36.3	38.4	40.6	42.6
110	37.7	38.7	41.8	43.9
120	39.0	39.9	43.0	45.1
130	40.2	41.1	44.1	46.2
140	41.3	42.1	45.1	47.3
150	42.3	43.1	46.0	48.2
160	43.2	44.0	46.9	49.1
170	44.6	45.1	47.8	50.0
180	45.0	45.6	48.5	50.8
190	45.8	46.4	49.3	51.6
200	46.6	47.1	50.0	52.3

Phase 1 of the experiment included collecting the participant's lifting capacity as well as their maximum acceptable weight limit (MAWL). There were two kinds of lifts that the participant completed and the order the lifts were completed was randomized to decrease the variability. The first kind of lift, which can be seen in Figure **3-1** below, was completed using the torso muscles. The participant was required to stand with their legs straight, but not locked, while using his or her torso muscles to pull up on a strength tester. The strength tester monitored the force exerted by the subject by mimicking a lift an object placed on the ground, while recording the static strength of the subject for five seconds. The strength tester outputted the results in pounds. The second kind of lift was completed using the leg muscles and the participant was asked to stand with his or her legs shoulder width apart and to keep his or her legs bent while lifting. This position caused the participant's hands to be in between his or her legs while he or she completed the lift. The position of the participant during this lift can be seen in Figure **3-2** below. The participant completed each type of lift three times with a minute rest in between. Circular stickers were placed on the participant's right wrist, elbow, shoulder, hip, knee, and ankle. A picture was taken for each kind of lift and the stickers were used to analyze the posture of the participant during the lifts and the compression on the spine. The results of this analysis will appear in Lorna Cintron's dissertation (2012). After the six lifts were completed, the participant moved into the second part of Phase 1.

Figure **3-1**: Participant Performing a Torso Lift

Figure **3-2**: Participant Performing a Leg Lift

Part 2 of Phase 1 had the participant determine what their maximum acceptable weight limit (MAWL) would be during the conditions specified. The situation was that the participant's job was to lift a box from the ground to a stool back to the ground every 15 seconds during an eight hour work day with a lunch break and two additional short breaks. For this simulation, the participant stood in front of an empty box on the ground and every 15 seconds was asked to lift the box up on a stool and then back down again on the ground, which can be seen in Figure **3-3** below. A metronome on the computer helped count the time between the lifts. Each round consisted of four lifts for a total of one minute of repetitive lifting. At the end of each round, the participant was asked if that was the maximum they could lift during the given conditions. The rounds continued, increasing the weight in the box by a small or large amount, until the participant concluded the weight in the box was the maximum they could lift during the conditions specified. At this point the box was weighed and the weight in pounds and the number of tries to achieve the MAWL was recorded. This concluded Phase 1 of the experiment, but if the participant was classified as a normal body type, they were invited to participate in Phase 2 of the experiment.

Figure **3-3**: Participant Lifting Box from Ground to the Stool

Only the participants, who were classified as normal, were eligible for Phase 2 of the experiment. The participants had to perform the two kinds of lifts three times in three different situations, with added girth, with added weight, and with added weight and girth. The order that this was completed was randomized for every participant to decrease the effect of order on lifting capability. Added girth was simulated by having the participant wear a pregnant belly that weighed less than a pound. This can be seen in Figure **3-4**. In order to simulate added weight, the participant wore an exercise weight vest filled with about 19.7 pounds, which can be seen in Figure **3-5**. Lastly, the participant wore both the pregnant belly and exercise weight vest to simulate an obese person, which can be seen in Figure **3-6**. Pictures were taken throughout Phase 2 in order to determine the F compression force, which will be analyzed in Lorna Cintron's dissertation (2012). The completion of these additional lifts concluded the research study and the participants were paid for their time completing the study.

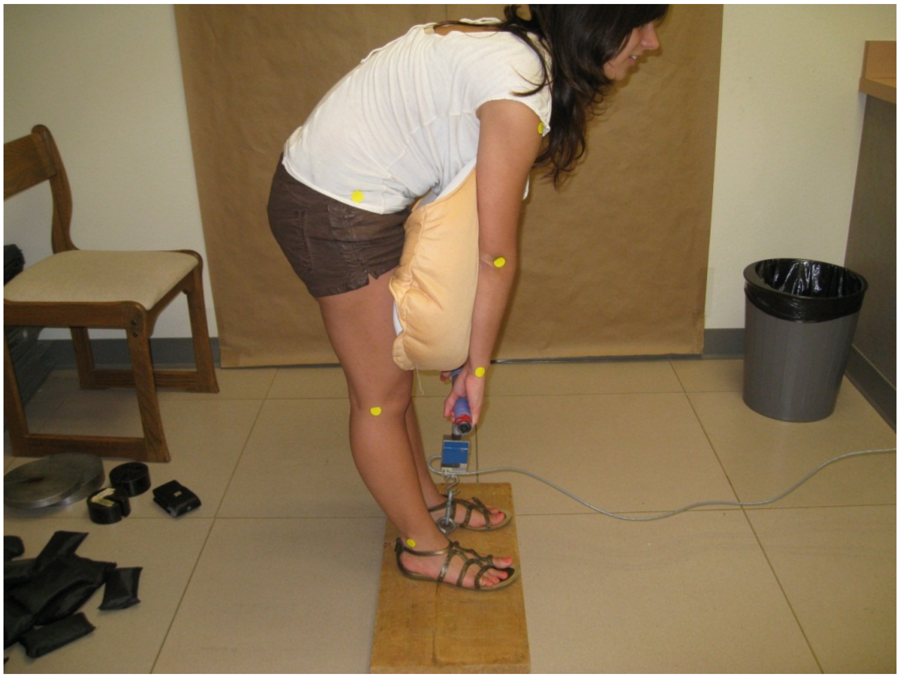


Figure **3-4**: Normal participant performing a torso lift with the added girth

Figure **3-5**: Normal participant performing torso lift with added weight

Figure **3-6**: Normal participant performing torso lift with added weight and girth

Chapter 4

Results and Analysis

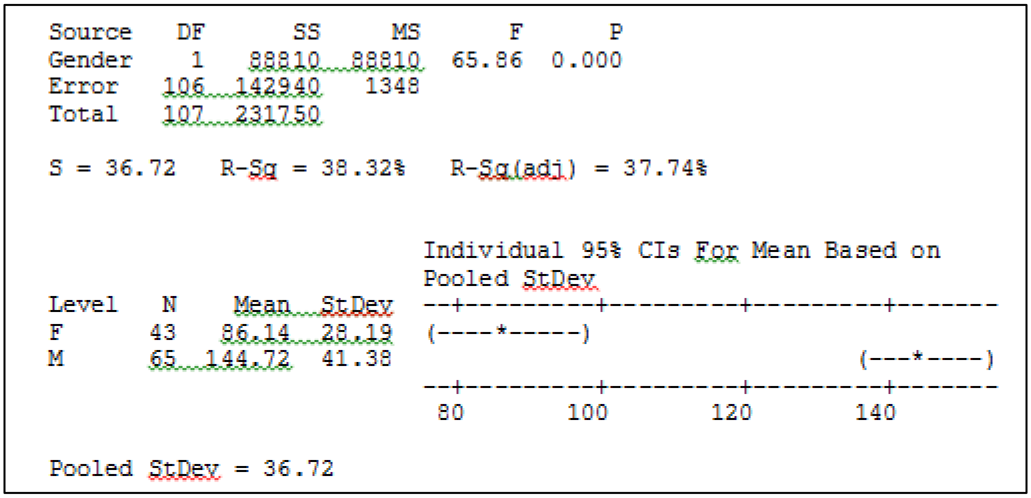
4.1 Phase 1 Results and Analysis

The raw data from Phase 1 can be found in Appendix A in Table **A-2**.

4.1.1 ANOVA Analysis for Gender

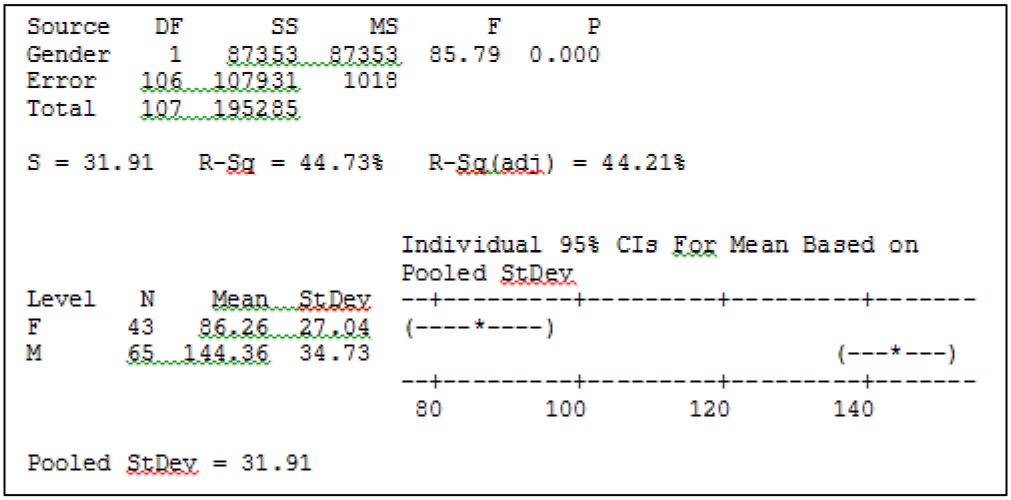
In order to determine if gender was a significant effect for lifting capability, an analysis of variance (ANOVA) was performed in Minitab. Tables **4-1**, **4-2**, and **4-3** show the ANOVA for the three outputs, lifting capacity using leg muscles, lifting capacity using torso muscles, and the maximum acceptable weight of lifts (MAWL). The results show that there is a difference in the lifting capacity between the male and female samples. This significance was used in the regression and general linear model analyses that were completed afterwards.

Table **4-1**: One-way ANOVA: Leg Average versus Gender (Minitab)



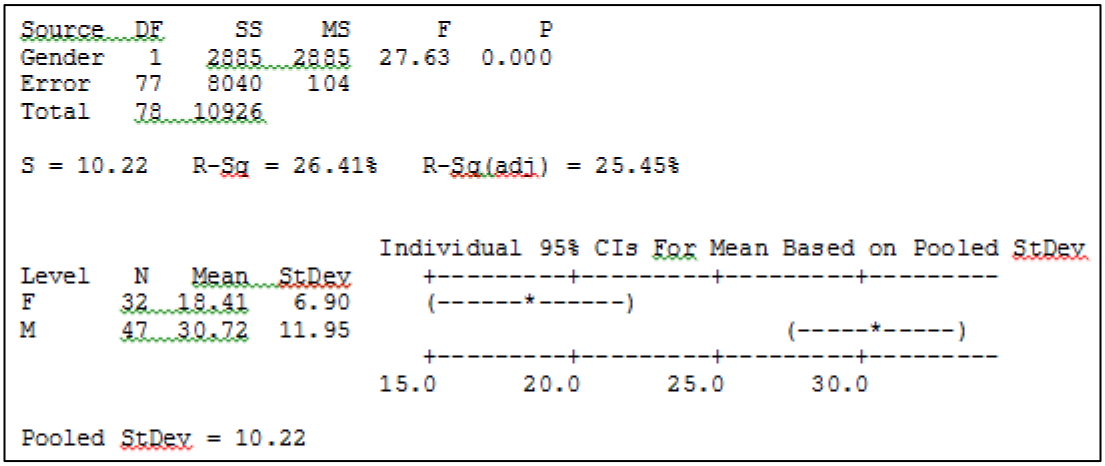
```
Source   DF      SS     MS       F      P
Gender    1   88810  88810   65.86  0.000
Error   106  142940   1348
Total   107  231750

S = 36.72   R-Sq = 38.32%   R-Sq(adj) = 37.74%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level    N    Mean  StDev  --+---------+---------+---------+-------
F       43   86.14  28.19  (----*-----)
M       65  144.72  41.38                                (---*----)
                           --+---------+---------+---------+-------
                            80      100       120       140

Pooled StDev = 36.72
```

Table **4-2**: One-way ANOVA, Torso Average versus Gender (Minitab)



```
Source   DF      SS     MS       F      P
Gender    1   87353  87353   85.79  0.000
Error   106  107931   1018
Total   107  195285

S = 31.91   R-Sq = 44.73%   R-Sq(adj) = 44.21%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level    N    Mean  StDev  --+---------+---------+---------+-------
F       43   86.26  27.04  (----*----)
M       65  144.36  34.73                                (---*---)
                           --+---------+---------+---------+-------
                            80      100       120       140

Pooled StDev = 31.91
```

Table **4-3**: Maximum Acceptable Weight Limit (lbs) Separated by Gender (Minitab)

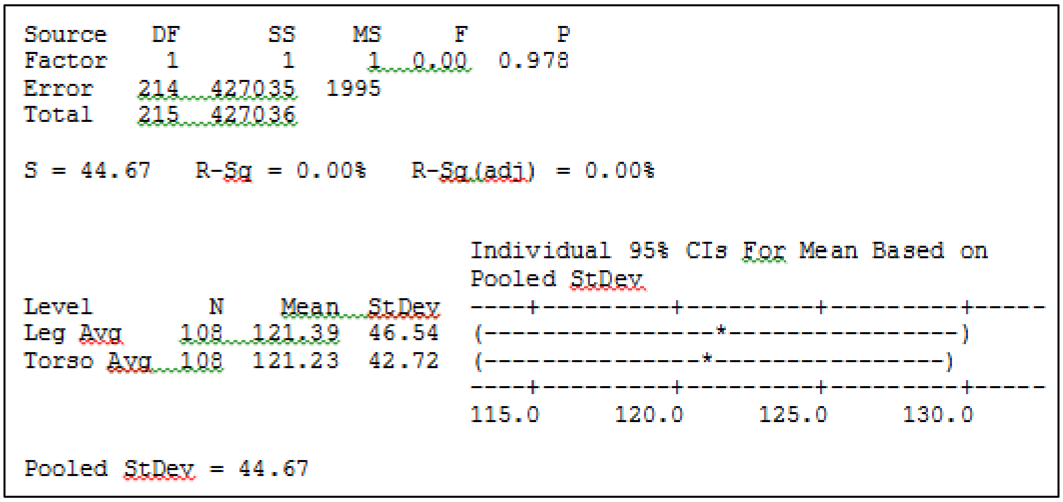


```
Source  DF     SS    MS      F      P
Gender   1   2885  2885  27.63  0.000
Error   77   8040   104
Total   78  10926

S = 10.22   R-Sq = 26.41%   R-Sq(adj) = 25.45%


                          Individual 95% CIs For Mean Based on Pooled StDev
Level   N   Mean  StDev   ---------+---------+---------+---------
F      32  18.41   6.90   (------*------)
M      47  30.72  11.95                       (-----*-----)
                          ---------+---------+---------+---------
                          15.0      20.0      25.0      30.0

Pooled StDev = 10.22
```

4.1.2 Comparison between Leg and Torso Lift Averages

In order to see if there was difference between the average lifting force for the lifts using the leg muscles versus using the torso muscles, an ANOVA was performed, which can be seen in Table **4-4**. Proper lifting technique has determined that lifting with the legs is preferred to avoid injury. The results of the ANOVA showed that there was no significant difference between using the leg muscles versus the torso.

Table **4-4**: One-way ANOVA: Leg Average, Torso Average (Minitab)

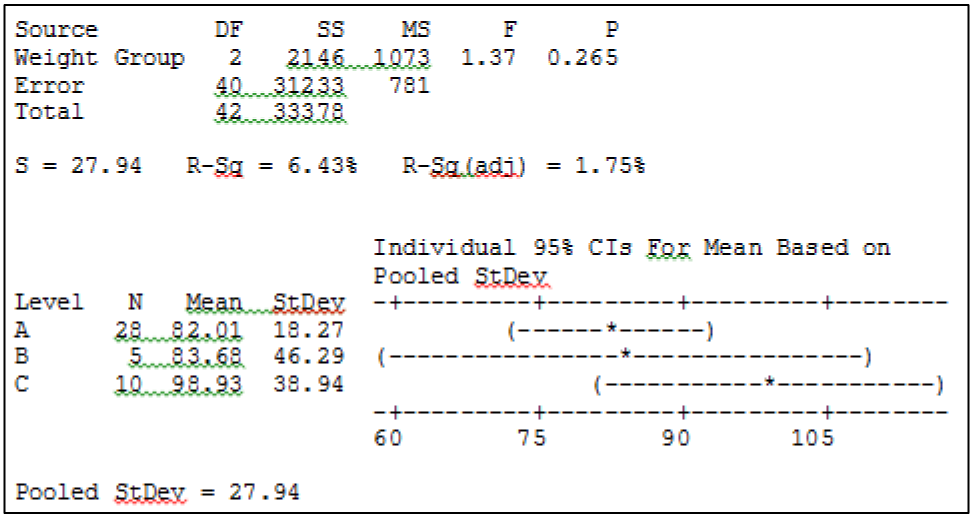


```
Source    DF      SS    MS     F      P
Factor     1       1     1  0.00  0.978
Error    214  427035  1995
Total    215  427036

S = 44.67   R-Sq = 0.00%   R-Sq(adj) = 0.00%


                                Individual 95% CIs For Mean Based on
                                Pooled StDev
Level         N    Mean  StDev  ----+---------+---------+---------+-----
Leg Avg     108  121.39  46.54  (----------------*----------------)
Torso Avg   108  121.23  42.72  (---------------*----------------)
                                ----+---------+---------+---------+-----
                                115.0     120.0     125.0     130.0

Pooled StDev = 44.67
```

4.1.3 Significance of Weight Category on Outputs

The next analysis completed was to perform ANOVA to see if there was significant difference between the weight groups for each of the outputs. Since gender was found to be a significant factor, the three tests were run for each gender type. All the results of all the ANOVA tests showed that there was no significant difference between the weight categories. A sample of this analysis can be seen in Table **4-5**. Further analysis was then run to see if there was a better way to determine a person's lifting capacity based on their weight or body fat.

Table **4-5**: One-way ANOVA Leg Average versus Weight Group (Minitab)



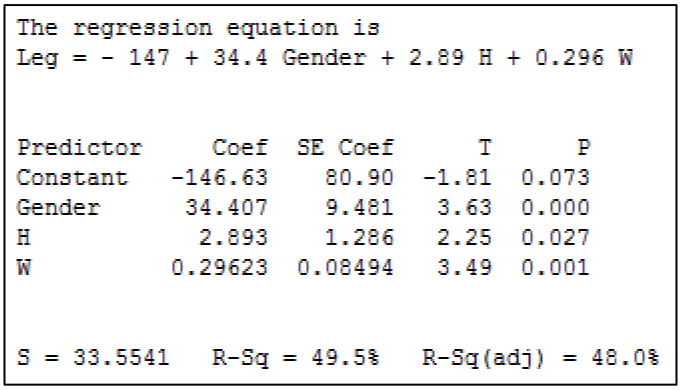
```
Source        DF     SS    MS     F      P
Weight Group   2   2146  1073  1.37  0.265
Error         40  31233   781
Total         42  33378

S = 27.94   R-Sq = 6.43%   R-Sq(adj) = 1.75%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N   Mean  StDev  -+---------+---------+---------+--------
A      28  82.01  18.27           (------*------)
B       5  83.68  46.29  (----------------*----------------)
C      10  98.93  38.94                (-----------*-----------)
                         -+---------+---------+---------+--------
                         60        75        90        105

Pooled StDev = 27.94
```

4.1.4 Regression and General Linear Model Analysis

The next analysis performed required defining some of the factors using coded variables. For gender, 0 was defined for the female participants and 1 was defined for the males. For the weight groups, 1 was defined as for the normal participants, 2 for overweight, and 3 for obese. Lastly, body weight was defined in another way using two coded variables, Norm and Over. Normal participants were defined as 1 and 0, overweight were defined as 0 and 1, and obese were defined as 1 and 1, respectively. For both the regression and general linear model analysis, the gender variable was always used since it proved to be significant in the earlier analysis. Different combinations of the variables were ran to determine the best model for predicting lifting capacity using leg muscles, back muscles, and maximum acceptable weight of lift. The complete analysis can be found in Appendix B in Table **B-1**, Table **B-2**, and Table **B-3**.

For the analysis of the strength using the leg muscles as the response, using three variables produced the best results, using two variables produced slightly worse results, and using four variables produced variables that had p values over 0.1. The best regression model was found using gender, height, and weight as the predictors. The regression equation can be seen in Table **4-6** and the R-squared value was 49.5%. The General Linear Model produced the same results.

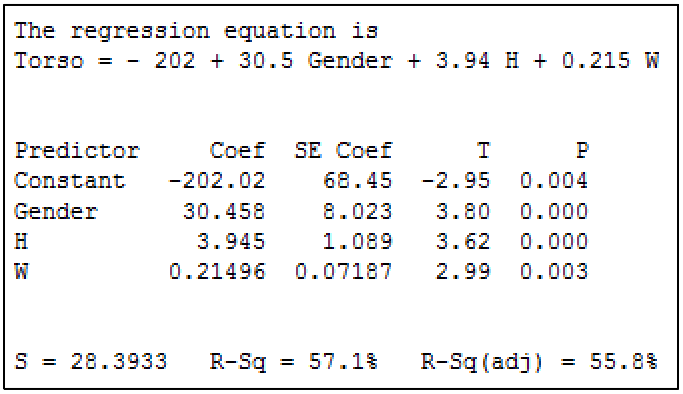
Table **4-6**: Regression Analysis of Leg Average and Gender, Height, and Weight (Minitab)



```
The regression equation is
Leg = - 147 + 34.4 Gender + 2.89 H + 0.296 W


Predictor      Coef  SE Coef      T      P
Constant    -146.63    80.90  -1.81  0.073
Gender       34.407    9.481   3.63  0.000
H             2.893    1.286   2.25  0.027
W           0.29623  0.08494   3.49  0.001


S = 33.5541   R-Sq = 49.5%   R-Sq(adj) = 48.0%
```

For the analysis of the strength using torso muscles as the response, p values of over 0.1 appeared when using two, three, and four variables. Using three variables once again proved to give the best overall results. Using gender, height, and the percent body fat from the scale produced the highest R-squared value of 57.2% for the regression model. On the other hand, the second highest R-squared value of 57.1% was the same one used to predict the leg response and was extremely close to the highest model. In order to be consistent with the previous results, this was the model that was chosen. The results of this model can be seen in Table **4-7**. The General Linear Model produced the same results.

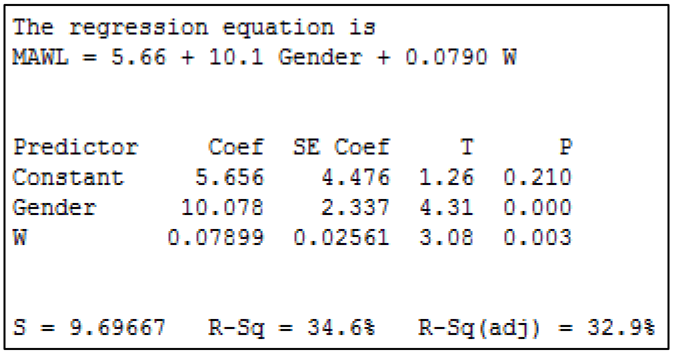
Table **4-7**: Regression Analysis of Torso Average and Gender, Height, and Weight (Minitab)



```
The regression equation is
Torso = - 202 + 30.5 Gender + 3.94 H + 0.215 W


Predictor      Coef  SE Coef      T      P
Constant    -202.02    68.45  -2.95  0.004
Gender       30.458    8.023   3.80  0.000
H             3.945    1.089   3.62  0.000
W           0.21496  0.07187   2.99  0.003


S = 28.3933   R-Sq = 57.1%   R-Sq(adj) = 55.8%
```

The last response that was analyzed was the maximum acceptable weight of lifts. This proved to the most difficult response to model because only a few of the results did not have p values over 0.05. The best model had an R-squared value of 34.6% and contained the variables gender and weight. These results can be found in Table **4-8** below. The General Linear Model produced very similar results.

Table **4-8**: Regression Analysis of MAWL and Gender and Weight (Minitab)

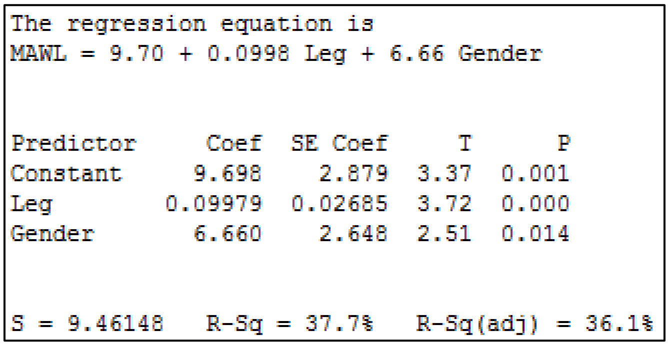


```
The regression equation is
MAWL = 5.66 + 10.1 Gender + 0.0790 W


Predictor      Coef  SE Coef     T      P
Constant      5.656    4.476  1.26  0.210
Gender       10.078    2.337  4.31  0.000
W           0.07899  0.02561  3.08  0.003


S = 9.69667   R-Sq = 34.6%   R-Sq(adj) = 32.9%
```

One important thing to observe that the R-squared value of the MAWL model, 34.6%, is a lot lower than the R-squared values from the Leg and Torso models, 49.5% and 57.1% respectively. MAWL depends on the subject deciding whether or not they can continue to lift a greater amount, making this response subjective and hard to fit a model to. In addition, some people were a lot more comfortable with repetitive lifting and had higher MAWL values. It is possible that people have a greater strength; therefore, using their leg and torso averages was hypothesized to find better results.

In order to find a better model for MAWL, the responses from the leg and torso muscles were used in the regression and General Linear Model. The best regression model was found using gender and leg average with an R-squared value of 37.7%. The results can be found in Table **4-9** found below. The General Linear Model produced similar results. This model still was not nearly as good as the models from the leg and torso averages; therefore, it was decided that the MAWL test does not represent the lifting capability of the individual very well and that more research should be completed to improve the MAWL test. In addition, having participants who are used to repetitive lifting may improve these results.

Table **4-9**: Regression Analysis of MAWL and Gender and Leg Average (Minitab)



```
The regression equation is
MAWL = 9.70 + 0.0998 Leg + 6.66 Gender


Predictor      Coef   SE Coef     T      P
Constant      9.698     2.879  3.37  0.001
Leg         0.09979   0.02685  3.72  0.000
Gender        6.660     2.648  2.51  0.014


S = 9.46148   R-Sq = 37.7%   R-Sq(adj) = 36.1%
```

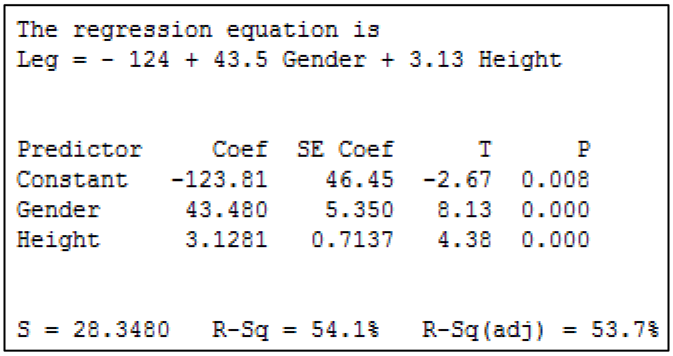
Gender, height, and weight were found to be significant factors in predicting the lifting capacity using the leg and torso muscles. Even though the calculation of BMI uses the height and weight, the models produced using BMI were not as good or had p values of over 0.5. The two ways to define the weight category, by weight category and the Norm and Over coded variables, of the participant also did not produce good models. Defining the body percent using the scale or the caliper produced good models but were not the best models. This could be due to the fact that the body fat percent might not accurately model the strength of the torso and leg muscles.

4.2 Phase 2 Results and Analysis

Phase 2 was harder to analyze than the first. The raw data from Phase 2 can be found in Tables **B-4** and **B-5** in Appendix B. The initial ANOVA tests did not produce conclusive results. In order to further analyze the data, the weight category and the coded variables for Norm and Over were not used. Instead, two more coded variables were defined, Weight and Girth. The data from Phase 1 of the experiment was defined with 0 for Weight and 0 for Girth. When the participant was wearing just the belly, weight was defined as 0 and girth was defined as 1. When the participant was wearing the weight vest, weight was defined as 1 and girth was defined as 0. Lastly, when the participant was wearing both the weight vest and the belly, weight was defined as 1 and girth was defined as 1.

Regression and general linear model tests were run in Minitab to determine if it was the added weight, added girth, or both that affects the lifting capability. First, the leg average was analyzed and the best regression model was found to have an R-squared value of 54.1% using gender and height. This can be seen below in Table **4-10**. The results from the general linear model were the same. The models using the weight and girth coded variables produced p values above 0.5, concluding that the added weight and girth did not make much difference in the participant's lifting capability.

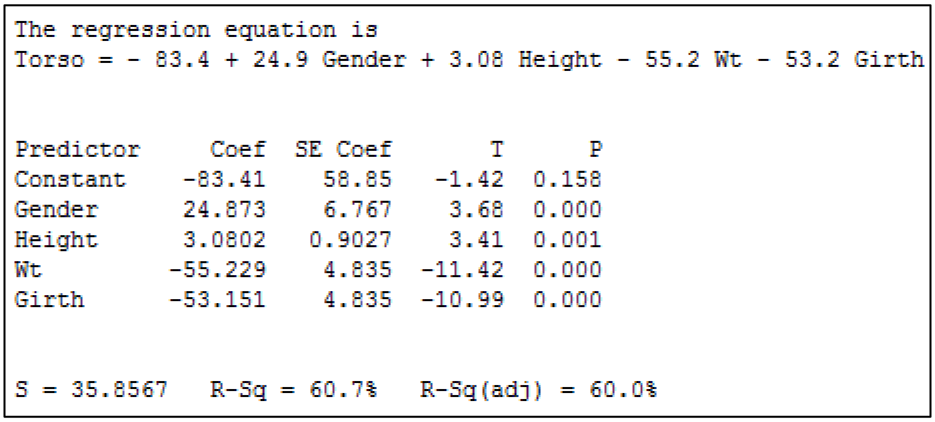
Table **4-10**: Regression Analysis of Leg Average and Gender and Height



```
The regression equation is
Leg = - 124 + 43.5 Gender + 3.13 Height


Predictor      Coef  SE Coef      T      P
Constant    -123.81    46.45  -2.67  0.008
Gender       43.480    5.350   8.13  0.000
Height       3.1281   0.7137   4.38  0.000


S = 28.3480   R-Sq = 54.1%   R-Sq(adj) = 53.7%
```

Next, the torso average was analyzed in the same manner. It was seen very quickly that when the weight and girth variables were not used, the R-squared values produced were below 15%. Using this observation, several regression and general linear models were run with the weight and girth variables. The best regression model produced an R-squared value of 60.7% using gender, height, weight, and girth. This can be seen below in Table **4-11**. The General Linear Model produced the same results. The R-squared value of 60.7% is also higher than the results from the leg average, which produced an R-squared value of 54.1%.

Table **4-11**: Regression Analysis of Torso Average and Gender, Height, Weight, and Girth



```
The regression equation is
Torso = - 83.4 + 24.9 Gender + 3.08 Height - 55.2 Wt - 53.2 Girth


Predictor     Coef  SE Coef       T      P
Constant    -83.41    58.85   -1.42  0.158
Gender      24.873    6.767    3.68  0.000
Height      3.0802   0.9027    3.41  0.001
Wt         -55.229    4.835  -11.42  0.000
Girth      -53.151    4.835  -10.99  0.000


S = 35.8567   R-Sq = 60.7%   R-Sq(adj) = 60.0%
```

When the torso lifts are performed during this phase, the participant’s torso muscles also had to work with an extra load on their back. It was then concluded that the added weight and girth affected the lifting capacity using the torso muscles, but not when using the leg muscles.

Chapter 5

Summary, Conclusion, and Future Research

5.1 Summary and Conclusions

When completing a manual lifting task in the work place, the worker puts his or her body risk unless proper precautions are taken into account. As a result of high back injury rates, the National Institute of Occupational Safety and Health (NIOSH) created the lifting guidelines that help determine the recommended weight limit (United States, 1994). These guidelines take in account the position of the item relative to the lifter's center of mass in terms of the horizontal and vertical distances. In addition the distance moved, the amount of twist in the body during the initial position, the frequency of the lift, and the type of hold on the item is all used in the equation (United States, 1994). Companies can then use these guidelines to determine if certain job tasks needs to be reevaluated (United States, 1994). One limitation of this equation is that it does not take in account the weight and height of the lifter.

The trends in the United States and the world have shown a rise in obesity. From 2009 to 2010, it was seen that about 36% of United States adults 20 years old and over were obese (Ogden et al., 2012). Several studies have found that there are higher costs associated with obese adults (Shuford, 2010; Finkelstein et al., 2010). Several research studies have found that obese adults are more at risk for injuries and developing some illnesses and diseases (Xiang et al., 2005; Heuch, 2010; Pollack et al, 2007). The cost of obesity and the higher risk of injury has made it important for researchers and NIOSH to look into the effects of body weight on lifting capabilities.

In 1981 NIOSH developed the first lifting guidelines in order to decrease the number of back injuries and revised them in 1991 to reflect new findings (Waters et al., 1993). The three criteria used to develop the lifting guidelines were biomechanical, physiological, and psychophysical (Waters et al., 1993). This research satisfies the biomechanical criterion, since the lifting capabilities of the participants were measured, and the data from this research will be used to calculate the force of compression sustained on the spine of the participant. This analysis can be found in Lorna Cintron’s dissertation (2012). In addition, the psychophysical criterion was satisfied by the MAWL test that was completed by the participants.

There is currently a lack of research in the area of lifting and body weight. Since obese people are at a higher risk for injury, it is important that research is completed to know if their recommended weight limit should be adjusted. Phase 1 of this research looked to see if the lifting capability was affected. The lifting guidelines define the object to be lifted relative to the center of mass of the participant. Obese adults have to account for the extra girth around the waist and this may impact their lifting capacity. In addition, the extra weight the obese adults have gained may also have an impact. These hypotheses were addressed in Phase 2 of the experiment. Many results were analyzed from the completion of the experiment.

For Phase 1, the initial analysis of all the outputs showed that males were able to lift more than females, indicating that gender was a significant factor. The ANOVA test that was performed was not able to conclude if there was a difference between the averages of the leg lifts to the torso lifts. The ANOVA test also did not indicate a difference between the weight categories. To further analyze Phase 1, regression and general linear models were created in Minitab. In order to predict the lifting capacity using leg muscles, the best model was found using gender, height, and weight as the predictors, which had an R-squared value of 49.5%. The best model found for predicting the lifting strength of a participant using the torso models was found using gender, height, and weight, which had an R-squared value of 57.1%. It is interesting to note that BMI, body fat, or weight category were not found to produce the best regression and general linear models. The analysis of MAWL in the same manner as the leg and torso averages did not produce nearly as good as results. In order to improve these results, the leg and torso averages were used in the regression and general linear models, to decrease the variability from the subjective MAWL test. The best regression model had an R-squared value of 37.7%, which used gender and leg average as the predictors. This model did not produce as good results as the leg and torso models; therefore, it was concluded that the MAWL test was not a good representation of the participant's lifting capacity due to the subjectivity of the test.

Phase 2 was found harder to analyze than Phase 1. The ANOVA tests did not produce good results; therefore, regression and general linear models were performed. The best regression model for the lifting capacity using the leg muscles was found to have an R-squared value of 54.1% with gender and height as the predictors. Since the weight and girth coded variables did not produce acceptable models, it was concluded that the added weight and girth did not make a difference in a participant's lifting capability using their leg muscles. The model for the torso average was found to have a slightly higher R-squared value of 60.7% using gender, height, and the weight and girth coded variables as the predictors. The additional weight and girth did have a significant effect due on the lifting capacity of the participant using the torso muscles since there was an additional force in the opposite direction to work against.

The past research in relation to obesity and lifting has shown that more research needs to be completed to further understand the relationship between obesity and lifting. The research completed by Xu et al. showed that the obese participants had higher measures for the dynamics of lifting motion than the normal participants (2008). The authors felt that a limitation of their study was that obesity was measured based on height and weight. In another study, using the MAWL test in the non-obese and obese participants groups, gender lifting height, and lifting frequency were found to be significant (Singh et al., 2009). This was similar to the results of the experiment in this thesis where gender was found to be a significant factor. In addition, the research found that the obese participants had grown accustomed to the additional weight and were capable of lifting more, which also agreed with the research of obesity and the lifting motion of the participants (Singh et al., 2009; Xu et al., 2008). The research from this thesis was able to provide additional conclusions to the research related to lifting and obesity. The results of this experiment and the previous research can now be used by NIOSH to revise the current lifting guidelines to include a way to classify obesity. In addition, they can encourage more research to be completed in order to better understand the relationship between lifting and obesity.

5.2 Areas for Future Research

There has not been a lot of research on lifting capacity based on the body weight of the individual. This research and the previous research has shown that there might be more factors to consider for truly determining a person's lifting capacity. One of these factors might be the physical activity of the individual outside of work. During this research study, there were participants who completed heavy lifting as part of their daily activities, resulting in a higher MAWL value. Also, a lot of the participants were students and were not used to repetitive lifting and as a result might not have been to judge accurately of how much they were comfortable lifting during an eight hour work day. In future studies participants from industry who complete repetitive lifting in their daily work tasks should be used since they have a better understanding of their capabilities. In addition, more research should be done to see if there are better ways on classifying the obesity individuals. This research showed that the weight category, the body mass index, and the percent body fat were not significant effects in the models, but height, weight, and gender were often found to be significant. The prevalence of obesity will continue to be high until lifestyles of people change and more initiatives are geared towards people keeping off extra weight. Since obese individuals have more of likelihood of developing several diseases and illnesses and a higher risk for injury, it is important that more research should be completed to see the relationship with body weight and lifting capacity in order to help employees complete their work tasks safely.

Appendix A Raw Data from Research Study

Table **A-1**: Participant Body Composition

Subject ID	Gender	Height (in)	Weight (lbs)	BMI	Weight Group	% Body Fat Scale	% Body Fat Caliper
1	M	70	177.8	25.7	B	23.5	17.7
2	M	70	169.4	24.5	A	21.2	22.2
3	F	64	150.9	26.1	B	30.7	30
4	F	65	202.7	33.7	C	37.2	34
5	M	71	185	25.8	B	23.5	15
6	M	71	163.4	22.8	A	18	12.5
7	M	69	168.5	24.9	A	21.7	20.2
8	M	68	145.6	22.3	A	17	22.2
9	F	66	138.6	22.5	A	24.3	24
10	M	69	185.2	27.4	B	25.4	24
11	M	65	162	26.9	B	24.7	22.2
12	F	68	157	24.1	A	26.7	26.5
13	M	71	167.2	22.1	A	16.6	13.9
14	F	65	189.1	31.5	C	35.3	29
15	F	62	131.4	24.1	A	27.4	27
16	M	72	161.2	22	A	16.5	17.7
17	F	66	154.2	25.1	B	28.1	28
18	M	68	148.1	22.7	A	17.7	13
19	F	68	148.6	22.8	A	24.5	26.5
20	M	67	153.4	24	A	20.2	18
21	F	64	151.1	26.1	B	29.9	32.2
22	M	73	181.7	26.2	B	23.5	11.5
23	M	73	217	28.7	B	27	18
24	M	68	142.7	21.9	A	16.3	8.5
25	F	65	129.9	21.6	A	22.6	31.2
26	M	70	174.1	23.8	A	19.9	18
27	F	64	179	29.8	B	33.7	34
28	M	68	155.8	23.9	A	20.2	19.2
29	M	68	191.8	29.4	B	27.9	24.5
30	F	66	192	31	C	-	39
31	F	66	200	32.5	C	36	34.8
32	F	61	108.3	20.7	A	22	21.6
33	M	78	223.4	25.3	B	22.4	17
34	M	67	198.6	30.5	C	29	21.2

Subject ID	Gender	Height (in)	Weight (lbs)	BMI	Weight Group	% Body Fat Scale	% Body Fat Caliper
35	M	75	176.5	22.1	A	16.5	10.2
36	M	71	173.6	24.2	A	20.3	18
37	M	69	150.6	22.2	A	17.1	16.1
38	M	70	285.2	41.3	C	37.8	32
39	M	70	182.8	26.4	B	23.7	14.7
40	M	74.5	301	39	C	36.3	28.8
41	F	64	142.2	24.5	A	27.9	30.2
42	M	71	182	25.4	B	22.4	19.5
43	F	60	104.7	20.5	A	21.9	23.4
44	M	68	134.4	20.6	A	12.9	12.1
45	F	67	156.4	24.4	A	27	30.2
46	F	66	133.7	21.7	A	22.8	27.8
47	M	73	147.2	8.5	A	10.5	12.1
48	F	65	116.7	19.4	A	18.5	23.4
49	M	72	219.9	28.5	B	26.7	17
50	F	65	124.2	21.4	A	22.8	25
51	F	69	144.3	21.3	A	21.8	26.5
52	M	70	155.4	22.4	A	17.2	12.1
53	F	65	124.9	20.8	A	21.5	25
54	F	64	129.1	22.3	A	24.1	27.8
55	F	68	147	22.5	A	23.8	29.1
56	M	71	163.5	22.8	A	17.8	16.3
57	M	75	146.1	18.3	A	7.2	8.1
58	M	70	205.4	29.7	B	28.1	21.2
59	M	73	190	23.8	A	19.7	12.9
60	M	66	156.2	25.4	B	22.4	16.3
61	M	74	209	27.1	B	24.8	16.3
62	M	70	173.1	25	B	21.7	19
63	F	64	140.1	24.2	A	27.4	32.2
64	M	70	202.3	29.2	B	27.7	20.2
65	F	66	136.4	22.2	A	23.5	26.5
66	F	64	131.9	22.7	A	24	26.5
67	F	65	133.6	22.2	A	23.9	26.5
68	M	72	131	17.9	A	5.8	14.7
69	F	66	169.4	27.6	B	31.3	29.1
70	M	77	182.6	21.7	A	15.8	15
71	M	65	182.2	30.3	C	28.7	24
72	M	66	174.3	28.3	B	26.7	24.8

Subject ID	**Gender**	**Height (in)**	**Weight (lbs)**	**BMI**	**Weight Group**	**% Body Fat Scale**	**% Body Fat Caliper**
73	F	64	114.1	79.7	A	19.5	21.6
74	M	69	173.2	25.6	B	22.6	19
75	M	70	169	24.4	A	20.8	14.7
76	F	69	135.6	19.6	A	18	23.4
77	M	71	171.6	24	A	19.8	19
78	F	64	142.2	24.6	A	27.5	27.8
79	F	61	109.2	20.8	A	22.3	25
80	M	69	164.1	24.2	A	20.8	17.7
81	F	63	287	50.8	C	45.6	33.1
82	M	68	178.9	27.4	B	25.5	21.2
83	F	64	134.1	23.1	A	25.5	23.4
84	F	63	133.4	23.5	A	26.7	25
85	M	71	169.2	23.6	A	19.4	6.7
86	M	63	135.1	23.9	A	19.8	18
87	M	68	168	25.7	B	22.9	20.7
88	F	65	123.9	20.6	A	21.6	24
89	M	69	168.3	24.9	A	21.4	19.5
90	M	74	181.1	23.5	A	19.2	20.2
91	M	65	129.9	21.6	A	15.3	13
92	M	72	177	24.2	A	20.4	15
93	M	68	204.5	31.4	C	29.9	25.5
94	M	67	168.8	26.4	B	23.9	16.3
95	M	68	153	23.4	A	18.8	27.8
96	F	62	128	23.5	A	26.7	25
97	M	73	175.6	23.2	A	18.8	21.2
98	M	67	130.6	20.4	A	12.7	11.2
99	F	64	209.5	36.2	C	38.8	30.2
100	F	64	194.2	33.5	C	37.1	33.1
101	F	66	183.7	30	C	33.7	31.7
102	M	74	313.8	40.7	C	37.4	27.6
103	M	71	302.8	42.3	C	38.8	29.9
104	M	71	219.9	30.7	C	29.5	25.6
105	M	71	256.5	35.8	C	34.1	34
106	F	64	203.3	35.1	C	38.2	38.7
107	F	60	267.2	52.4	C	46.6	42
108	M	72	250.4	34.2	C	32.6	29.2

Table **A-2**: Phase 1 Data

Lifting Posture Order	Leg Lift 1	Leg Lift 2	Leg Lift 3	Leg Average	Torso Lift 1	Torso Lift 2	Torso Lift 3	Torso Average	Number of Tries	MAWL (lbs)
2		154.3	146.6	150.450	115.5	142.7	140.7	132.967	2	23.9
2	162.7	115.9	167.4	148.667	150	157.7	154.1	153.933	3	22.8
1	64.3	35	37.7	45.667	69.5	48.7	50.8	56.333	4	14.7
1	125.6	139.4	134.3	133.100	124.2	139	149.3	137.500	4	11.7
1	200	200	200	200.000	200	200	200	200.000	4	40.9
1	98.8	31.2	75.7	68.567	86.1	87	69	80.700	4	22.8
1		102.1	125.6	113.850	95.6	114.4	107.1	105.700	4	29.8
2	114.4	123.4	106.4	114.733		125.6	115.9	120.750	3	27.8
2	91	77.3	93.7	87.333	93.7	55.7	79.7	76.367	4	19
1	70	64.2	89.4	74.533	97.6	120.7	109.5	109.267	5	46.1
1	72.3	69.1	56	65.800	125	125.9	147.5	132.800	6	44.8
1	96.9	77.8	113.1	95.933	86.8	80.9	58.7	75.467	3	13.1
1	184.5	128.1	128.1	146.900	129.1	145.3	144.3	139.567	2	23.8
1	59.4	54	58.9	57.433	112.8	66.3	66.3	81.800	4	13.6
2	76.2	93	92.9	87.367	84.3	94.9	101.4	93.533	5	21
2		164.1	151.6	157.850		147.2	147.2	147.200	2	25.8
1	74.5	71.9	85.7	77.367	72.8	87.4	84.4	81.533	3	13
1	137.6	101.5	120.9	120.000	76.9	85.5	115	92.467	4	30.9
2	91.6	97.1	98.3	95.667	80	109.5	126.9	105.467	3	25.7
1	108.8	95.5	101.5	101.933	71.6	128.1	90.1	96.600	3	21.2
2	59.3	78.7	60.9	66.300	63	58.7	56.2	59.300	4	25.9
2	129.1	195.2	149.8	158.033	200		200	200.000	5	55.1
1	131.8	132.7	139.7	134.733	139.7	144	148.8	144.167	4	40.8
1	160.1	185.5		172.800	137.2	127	129.8	131.333	2	23
2	60.1	71.1	71.1	67.433	78.3	84.3	88.6	83.733	2	14
2	200	200	180	193.333	136.8	145.9	140.5	141.067	3	48.8
2	64.7	56.4	74.3	65.133	50.9		54.7	52.800	2	23.9
2	99.2	75.3	133.1	102.533	129.1	117.9	114.4	120.467	4	25
2	140.4	139.9	132	137.433	161.2	126.8	173.2	153.733	4	26
2	106.2	88.6	108.3	101.033	142.2	120.3	86.2	116.233	3	25.7
1	106.2	77.3	92.2	91.900	115.2	86.2	83.7	95.033	4	27.7
2	60.5	62.2	57.7	60.133	34	61.3	50.2	48.500	4	11.5
2	176.4	200	200	192.133	187.2	200	200	195.733	3	26.6
2	200	200	200	200.000	144.5	144.5	174.8	154.600	4	30
1	200	140.9	141.9	160.933	155.2	200	185.8	180.333	3	30
2	112.3		128.2	120.250	148.8	131.5	134.7	138.333	3	28.3

Lifting Posture Order	Leg Lift 1	Leg Lift 2	Leg Lift 3	Leg Average	Torso Lift 1	Torso Lift 2	Torso Lift 3	Torso Average	Number of Tries	MAWL (lbs)
1	160.6	170.9	177.1	169.533	177.6	176.4	166.7	173.567	2	23.8
2	175.5	176.1	172.8	174.800	143.3	170.9	181.7	165.300	2	16.7
2	150	168	182	166.667	121.3	125.3	120.9	122.500	5	30.6
1	153.5	113.5	108	125.000	139.6	131.4	144.4	138.467	3	18.7
2	105.7	85	98.6	96.433	82.2	94.9	85.6	87.567	2	5.8
2	140.4	140.1	126.6	135.700	106.7	121.7	98.7	109.033	2	23.6
1	55.7	61.9	81.4	66.333	36	80.9	81.3	66.067	3	13
2	91.2	103.9		97.550	117.9	106.3	107.4	110.533	3	18.7
1	104	88.5	98.2	96.900	50.7	77.3	85.6	71.200	3	28.5
1	71.9	91.6	88.9	84.133		77.1	82.9	80.000	4	25.6
1	178.3	186.8	164.3	176.467	180.1	198.6	195.9	191.533	2	36.3
1	48.4	57.4	56	53.933	62.1	60.1	55.5	59.233	4	28.5
2	200		200	200.000	50.9	187	200	145.967	4	48.2
2	112.9	100.8	90.6	101.433	90.5	98.4	102.3	97.067	4	15
2		73	66.2	69.600		79.4	84.5	81.950	4	18.8
1	96.7	80.4	94.6	90.567	123.5	104.2	120.2	115.967	3	23.9
1	27.6	108.8	93.6	76.667	73.4	81.3	103.2	85.967	4	9.6
2	123	121	119.6	121.200	100.6	99.5	123.3	107.800	3	19.8
1	46.5	68.8		57.650	58.3	80.6		69.450		
2	152.9	132.5	167.6	151.000	132.3	151.3	199.5	161.033		
2	142.6	174.1	200	172.233	158.1	198	200	185.367		
2	197.5	200	198.5	198.667	179.9	171.8	173.8	175.167	3	21.1
1		135.2	67	101.100	159.1	170.8	72.2	134.033		
2	85.3	85.4	78.2	82.967	103.1	93.3	89.4	95.267	3	21.2
1		134.9	137.6	136.250	148.8		188.4	168.600	4	36.4
1	72.5	86	95.9	84.800	72.8		85.4	79.100	3	13.1
1	85.4	63.1	63.4	70.633	82.7	85.9		84.300		
1	95.9	96.6	119.1	103.867	140.6	146.4	160.9	149.300	4	35.6
1	146.7	112	115.5	124.733	113.3	118.7	127.9	119.967		
1	92.4	91		91.700	78.9	82.4		80.650		
1	64.6	79.5	73.5	72.533	53.6	62.7	76.8	64.367		
2	112	139.8	168.1	139.967	141.7		111.5	126.600		
2	166.2	160.7	164.9	163.933	146.1	158.9	188	164.333	4	16.9
1	96.6	200	197.7	164.767	200	197.7	200	199.233		
2	93.4		106.2	99.800	94	79.9	90.8	88.233	5	21
2	166.6	170.4	159	165.333	142.8	178.3	184.5	168.533	3	26.5
1	66.4	70.2	67.7	68.100	48.9	58.7	74	60.533	3	12.5
2		166.2	143.2	154.700		122.3	152.1	137.200	3	25.6

Lifting Posture Order	Leg Lift 1	Leg Lift 2	Leg Lift 3	Leg Average	Torso Lift 1	Torso Lift 2	Torso Lift 3	Torso Average	Number of Tries	MAWL (lbs)
1	196.2	200	200	198.733	194.8	200	190.7	195.167		
1	83.2	80.5	58.2	73.967	64.9	66.1	75.6	68.867		
1		124.7	155.8	140.250		129.5	137	133.250		
2	99.8	89.1		94.450	95.9	86.2	73.4	85.167		
2	90.6	91.4	103.1	95.033		122.8	103.8	113.300		
1	139.7	185.1	182.2	169.000		164	153.8	158.900		
1	85.9	134.7	137	119.200	117.8	124.8	106.7	116.433	5	31
2	135.5	149.3	148.9	144.567	176.9	170.2	174.7	173.933	3	21.1
1	81.5	92.7	81.2	85.133	87.4		79.7	83.550		
1	82.5	84.5	78.1	81.700	87.4			87.400		
1	139.1	162.9	166.7	156.233	117.1		142.3	129.700		
1	110.9	115.6		113.250	112.2	113.5	98.2	107.967		
2	120.2	117.6	122.3	120.033	95.9	105.1	97.4	99.467	3	21.2
2	64.4		62.9	63.650	62	64.9	54.1	60.333		
2	73.2	133.7	160.7	122.533	109.2	153.7	165.5	142.800		
1	188.2		175.8	182.000	194.4	197.8	195.9	196.033		
1	170.3	188.9	186.4	181.867	155.2	174.8	130.8	153.600		
1		133	142	137.500	171.1	174.2	180.5	175.267		
1		143.3	152.6	147.950		120.5	142.2	131.350		
1	116.9	90.7	106	104.533	107.6	153.6	133.3	131.500	4	35.4
1	100.3	107.4	112.4	106.700	111.4	97.3	106.7	105.133		
2	55.3	66.8	47	56.367	53.1	58.6	46	52.567	2	10.5
1	155.9	174.1	153.2	161.067	175.8	160.7	135.9	157.467		
2	104.6	96.2	90.4	97.067	101.3	128	143.9	124.400		
2	134.1	119.7	117.9	123.900	99.2	127.2	117.8	114.733	3	13
1	66.7	81.3	64.7	70.900	130.5	130.1	132.1	130.900	3	18.3
2	50.3	50.8	60.5	53.867	42.7	40	67.3	50.000	3	10.7
2	165	198	161	174.667	121	187	195.8	167.933	5	39.9
1	198	297	396	297.000	220	275	264	253.000	5	65
1	173.8	215.6	198	195.800	134.2	151.8	121	135.667	3	35.5
1	128	128	130	128.667	100	134	102	112.000	4	23.3
1	180	170	172	174.000	114	154	156	141.333	3	25.7
1	42	64	86	64.000	34	72	76	60.667	4	25.3
1	200	200	200	200.000	160	200	200	186.667	5	67.1

Table **A-3**: Phase 2 Results for Added Girth

Subject ID	**Leg Lift 1**	**Leg Lift 2**	**Leg Lift 3**	**Leg Lift Average**	**Torso Lift 1**	**Torso Lift 2**	**Torso Lift 3**	**Torso Lift Average**
2	163.8		140.4	152.100	138	138	122.3	132.767
6	52.3	60.4	65.2	59.300	62.2	62.2	39.7	54.700
7	89	101.2	99	96.400	89.4	99.3	95.5	94.733
8	109.7	114.9	108.9	111.167	106.2	114.4	104.3	108.300
9	87.7	89.9	76.6	84.733	79.3	80.5	78.2	79.333
12	67.3	60.4	60.4	62.700	57.2	56	58.1	57.100
13	138.8	142.6	140.8	140.733	129	125.7	122.3	125.667
15	70.6	58.2	59.5	62.767	64.6	67	70.6	67.400
16		147.2	171.8	159.500		177.5	158.6	168.050
18	116.7	82.1	94.5	97.767	76.7	113.5	179.8	123.333
19	81.8	64	81.7	75.833	95.1	118.4	108.3	107.267
20	140.9	100.6	120.1	120.533	72.7	83	107	87.567
24	162		141.3	151.650	136.9	136.9	141.8	138.533
25	69.6	67	67	67.867	69.7	77.8	84.8	77.433
26	164.5	179.6	181	175.033	138.3	119.5	87.3	115.033
28	109	95.3	107	103.767	94.4	106.2	107.6	102.733
32	34.4	38.4	45.2	39.333	56.2	53.9	43.6	51.233
36	62.2	97.9	94.1	84.733	103.1	48.6	102.4	84.700
43	59.4	55.6	63.4	59.467	61.1	61.1	61.1	61.100
44	190.9	187.1	127.7	168.567	135.9		173.3	154.600
45	79.1	67.3		73.200	109.3	97.6	88.7	98.533
46	40.4	85.5	85.8	70.567	70.2	72	78.8	73.667
47	159.1	137.5	166.7	154.433	152.2	138.8	146.1	145.700
50	95.6		105.3	100.450	80.7	100.8	84.5	88.667
51	53.3	56	55.4	54.900	79.8	53.3		66.550
52	134	133.7	162.1	143.267	99.6	104.1	114.2	105.967
54	99.6	110.2	98.8	102.867	115.8	100.2	99.6	105.200
55	79.8	104.8	62.3	82.300	117.7	108.6	53.5	93.267
56	152.7	169.1	178.2	166.667	162.1	186.1	158.8	169.000
57	190	200	200	196.667	168.1	191.9	184.2	181.400
59	149.5		65.3	107.400	110.1	61.9		86.000
63	66.9	69.7	72.9	69.833	56.4	83.3	60.4	66.700
65		97.4	100.5	98.950		96.3	101	98.650
66	59.4	73.7	76.6	69.900	84.4	87.6	86.5	86.167

Subject ID	**Leg Lift 1**	**Leg Lift 2**	**Leg Lift 3**	**Leg Lift Average**	**Torso Lift 1**	**Torso Lift 2**	**Torso Lift 3**	**Torso Lift Average**
67	70.3	94.3	82.8	82.467	85.3	89.9	83.6	86.267
68	155.1		154.5	154.800	116.5		175.3	145.900
70	177	193.6		185.300	200	198.1	200	199.367
75	185.1	197.2	190.9	191.067	180.6	193.2	197.4	190.400
76	73.9	69.6	68	70.500	55.6	61.6	65.6	60.933
77	170.2	169.6		169.900	80.5	113.7	136.4	110.200
78	116	110.7	133.2	119.967	119.8	119.8	105.9	115.167
79	103.7	120.5	126.8	117.000	93.6	101.4	103.1	99.367
80	180.2	193.3		186.750	152.6	136.5	145.8	144.967
83	87.4	87.6	88.9	87.967	77.7	79.9	85	80.867
84	76.3	62.8	71.7	70.267	83.9	84.7	79	82.533
85		179.1	140.3	159.700	129.2		131	130.100
86	147.4	114.9	112.4	124.900	92.3	85.5	92.6	90.133
88	65.6	65.9	50.8	60.767	62.3	65.9	66.2	64.800
89	170.9		157.6	164.250	160	175.3	184.9	173.400
90	154.4	184.5	200	179.633	180.5	176.5		178.500
91	182.1		110.7	146.400	200	120.2	174.6	164.933
92	175.3	175.6	174.9	175.267	181.2	176.2	155.1	170.833
95	101.2	106.1	121.1	109.467	117.9		124	120.950
97	124.5		135.6	130.050	157.9	140.5	138.9	145.767
98	115.1	134.4	121	123.500	133.2	141.6	120.3	131.700

Table **A-4**: Phase 2 Results for Added Weight

Subject ID	**Leg Lift 1**	**Leg Lift 2**	**Leg Lift 3**	**Leg Lift Average**	**Torso Lift 1**	**Torso Lift 2**	**Torso Lift 3**	**Torso Lift Average**
2	124.5	124.5	101.1	116.700	90	87.1	87.1	88.067
6	45.8	47.1	47.1	46.667	46.1	40.2	39.1	41.800
7	84.8	80.6	83.4	82.933	92.3	77.9	93.4	87.867
8	100.6	105	101.7	102.433	87.8	87.6	96.2	90.533
9	81.8	81.8	76.3	79.967	71.5	72.8	87.7	77.333
12	63.7	72.3	85.5	73.833	58.3	58.8	67.3	61.467
13	116	118.4	116.2	116.867	146.4	119.1	148	137.833
15	56.5	63.2	63.5	61.067	60.2	42.4	69.6	57.400
16	162.1	176.7	164	167.600	166.9	174.5	168	169.800
18	120.1	90.7	141.8	117.533	109.7	82.1	96.1	95.967
19	80.9	94.4	94.5	89.933	121.1	88.8	122.2	110.700
20	81.1	110.1	113.9	101.700	112.1	112.1	115.5	113.233
24	175.3	160.3	150.7	162.100	118	135	135.5	129.500
25	71.4	78.7	71.6	73.900	78.8	87.4	82.2	82.800
26	174.3	153.7	168.2	165.400	159.7	152.1		155.900
28	93.8	98	97	96.267	86.1	93.1	89	89.400
32	49	55.7	50	51.567	41.5	44.7	45.3	43.833
36	76.9	116.2	67	86.700	85.5	118.7	112.7	105.633
43	72	66.9	68.4	69.100	58.6	58.7	60.4	59.233
44	112.4	139.7	150.1	134.067	111	103.5	94.1	102.867
45	88.6	72.8	63.6	75.000	84.8	75.1	67.7	75.867
46	89.7	89	82.8	87.167	80.1	77.5	82.1	79.900
47	189	140.9	157.6	162.500	78.7	160.8	161.2	133.567
50	84.4	86.5	94.6	88.500	53.3	96.1	105.3	84.900
51	58.6	68.2	54.9	60.567	70.8	64.8	58.6	64.733
52	163.3	131.5	140.6	145.133	114.1	124.4	125.6	121.367
54	90.4	68.5	76.5	78.467	94.7	99.7	98.1	97.500
55	59.4		76.7	68.050	80.5	83.4	87.6	83.833
56	137.5	166.2	175.4	159.700	156.9	170.3	161.8	163.000
57	172.3	168.2	182.1	174.200		174.2	181.4	177.800
59	154.7	172.9		163.800	164.1	158.9	157.5	160.167
63		79.1	86.4	82.750	78.5	63.8		71.150
65	100.2	99.5		99.850	86.6		68.6	77.600
66	78.5	71.5	59.8	69.933	72.2	81.8		77.000
67	76.7		68.7	72.700	89.6	78	80	82.533

Subject ID	**Leg Lift 1**	**Leg Lift 2**	**Leg Lift 3**	**Leg Lift Average**	**Torso Lift 1**	**Torso Lift 2**	**Torso Lift 3**	**Torso Lift Average**
68		178.1	172.7	175.400	139.1	132	143.1	138.067
70	168.7	196.9	195.4	187.000	200	200	200	200.000
75	200	200	195.3	198.433	154.3	189.7	184.1	176.033
76	71.7	62.2	73.7	69.200	60.3		58.3	59.300
77	120.9	174.8		147.850	146.2	140.1	128.5	138.267
78	94.7	88.7	104.7	96.033	121.4	103.4	115	113.267
79		113	108.6	110.800	112.3	109.5	110.3	110.700
80	129.8	156.8	147.5	144.700	137.2		147.9	142.550
83		92.3	91.3	91.800	85.4	79	91.1	85.167
84	82.8	79.3	76.2	79.433	91.1	102	97	96.700
85	140.8	141.9	123.7	135.467	124.8	116.8		120.800
86	101.2	88	93	94.067	83.3	84.7	79.6	82.533
88	71.4	75.3	75.9	74.200	70.6	75.5	71.8	72.633
89	145.9	163.1	142	150.333	153.4		170.5	161.950
90	200	168.3	180.7	183.000	172.7	169.8	175.3	172.600
91	127	164	157.1	149.367	150.7	130.6	140.5	140.600
92	172.8	176.8	197.3	182.300	161.9	197.1		179.500
95	110	113.4	134.1	119.167	119.3		107	113.150
97	122.1		135.6	128.850	140.8	127.2	131	133.000
98	109.2	119.2	103.9	110.767	130.4	141.6	150.9	140.967

Table **A-5**: Phase 2 Results of Added Weight and Girth

Subject ID	**Leg Lift 1**	**Leg Lift 2**	**Leg Lift 3**	**Leg Lift Average**	**Torso Lift 1**	**Torso Lift 2**	**Torso Lift 3**	**Torso Lift Average**
2	135.7	129.6	129.6	131.633	82.8	98.2	108.1	96.3667
6	34	33.1	39.6	35.5667	31.9	40.1	34.1	35.3667
7	89.4	89.4	83.8	87.5333	104.9	104.9	88.7	99.5
8	92.3	107	110.4	103.233	101.7	89.4	89.4	93.5
9	79.6	88.6	88.9	85.7	81.8	81.8	60.4	74.6667
12	56	72.5	60.7	63.0667	42.5	54.3	69.9	55.5667
13	122.3	122.5	134.6	126.467	111.1	97.6	112.8	107.167
15	40.3	40.3	69.8	50.1333	42.5	39	57	46.1667
16		149	149	149		133.2	146.6	139.9
18	91.5	76.1	72.6	80.0667	28.4	103.1	116	82.5
19	74.9	76	70.3	73.7333	95	102.3	75.5	90.9333
20	123.1	118.2	114.9	118.733		102.5	78.9	90.7
24	147.3	157.2	136.6	147.033	128.2		121	124.6
25	76.9	74.3	70.7	73.9667	83.2	75.4	72.7	77.1
26	186.4	185.4		185.9	146.5	140.1	134.8	140.467
28	75.9	74.7	82.3	77.6333	61.5	74.4	92.4	76.1
32	35	52.9	49.8	45.9	46.7	52.1	55.6	51.4667
36	57	61.1	64	60.7	58.2	90.3	50	66.1667
43	66.6	56.7	61.1	61.4667	58.2	51.6	60.1	56.6333
44	112.3	139.7	150.1	134.033	111	103.5	94.1	102.867
45	74.7	79.6	75.4	76.5667	69.7	77.9	77.4	75
46	78	76.4	69.7	74.7	93.5	89.6	89.8	90.9667
47	157.2	152.3	76.7	128.733	195.2	181.1	136.7	171
50	95.6	80.6	78	84.7333	81.2		87.2	84.2
51	70.8	61.4	33.3	55.1667	65.1	70.8	57	64.3
52	143	133.4	145.7	140.7	110.1	139.2	105.4	118.233
54	101.7	114.9	99.1	105.233	120.1	117.3	101.7	113.033
55	91	96.3	106.2	97.8333	93.5	90.1	99.9	94.5
56	147.2	127.1	170.3	148.2	141.6	119.1	159	139.9
57	174.2	181.4	155.5	170.367	196.2	158	175.1	176.433
59	154.7	172.9		163.8	164.1	158.9	157.5	160.167
63	67.2	74.6		70.9	66.6	82.9	74.2	74.5667
65	126.5	96		111.25	104.2		78.8	91.5
66	75.6		62.9	69.25	65.8	85	80.5	77.1

Subject ID	Leg Lift 1	Leg Lift 2	Leg Lift 3	Leg Lift Average	Torso Lift 1	Torso Lift 2	Torso Lift 3	Torso Lift Average
67	78.4	66.1	73.5	72.6667	88.1	82.3	84	84.8
68	161.5	150.4	167.8	159.9	158.5		161.2	159.85
70	200	190.5	200	196.833		200	200	200
75	178.6	200	179.2	185.933	178.4	163.5	176.3	172.733
76	59.8	53	61.1	57.9667	58.2	55.9		57.05
77	131.1	134.2	168.7	144.667	155.7	132.4		144.05
78	101.6	106.2	96.8	101.533	124.6	105.4	124.3	118.1
79	99.2	113.4	126.3	112.967	96.9	109.8	116.5	107.733
80	172.2	168.3	163.1	167.867		153.2	168.7	160.95
83	84.2	93.4	101.6	93.0667	90.1	84.4	91.7	88.7333
84	65.8	77.1	62.1	68.3333	82	88.3	88.4	86.2333
85	133	153.2	122.1	136.1	141.4	141	139.2	140.533
86	108.3	116.1	99	107.8	91.7	98.8		95.25
88	63	61.6	67.6	64.0667	59.9	55.7	52.7	56.1
89	158	160.6	178.7	165.767	167.7	192	198.4	186.033
90	196.4	200	179.1	191.833	181.8	198.5	161.5	180.6
91	191.3	163.8	171.4	175.5	133.4	139.4	108.8	127.2
92	200		162.3	181.15		183.1	139	161.05
95		132.6	119.8	126.2	121.7	134.5	117.7	124.633
97	141	136.5	132	136.5	136.4	118.6	148.3	134.433
98	108.9	110.3	109.8	109.667	111.1	127.2		119.15

Appendix B Regression and General Linear Model Analysis

Table **B-1**: Phase 1 Leg Average P Values and R-squared Values

Analysis	**Gender**	**Height**	**Weight**	**BMI**	**Body Fat % Scale**	**Category**	**Body Fat % Caliper**	**Norm**	**Over**	**R-Sq**
Reg	0	0.002								43.6
Reg	0		0							47
Reg	0			0.102						39.9
Reg	0				0.008					42.4
Reg	0					0.016				41.6
Reg	0						0.11			39.8
Reg	0							0.006	0.013	43.2
Reg	0	0.027	0.001							49.5
Reg	0	0.001		0.046						45.7
Reg	0	0.001			0.002					48.6
Reg	0	0.001				0.009				47.2
Reg	0	0.001					0.046			45.7
Reg	0	0.001						0.003	0.011	48.5
Reg	0.001	0.054	0.006	0.669						49.6
Reg	0.027	0.284	0.196		0.709					49.5
Reg	0	0.069	0.03			0.678				49.6
Reg	0.048	0.102	0.004				0.366			49.9
Reg	0	0.053	0.078	0.972	0.519					50.1
GLM	0	0.027	0.001							49.48
GLM	0	0.001		0.046						45.7
GLM	0	0.001			0.002					48.61
GLM	0	0.001				0.009				48.55
GLM	0	0.001					0.046			45.69
GLM	0	0.001						0.003	0.011	48.55
GLM	0.001	0.054	0.006	0.669						49.57
GLM	0.027	0.284	0.196		0.709					49.45
GLM	0	0.053	0.078			0.533				50.1
GLM	0.048	0.102	0.004				0.366			49.88
GLM	0	0.053	0.078					0.972	0.519	50.1
GLM	0.032	0.377	0.172	0.643	0.677					49.56

Table **B-2**: Phase 1 Torso Average P values and R-squared Values

Analysis	**Gender**	**Height**	**Weight**	**BMI**	**Body Fat % Scale**	**Category**	**Body Fat % Caliper**	**Norm**	**Over**	**R-Sq**
Reg	0	0								53.4
Reg	0		0							51.6
Reg	0			0.298						45.3
Reg	0				0.028					47.7
Reg	0					0.044				46.8
Reg	0						0.259			45.4
Reg	0							0.032	0.126	47.1
Reg	0	0	0.003							57.1
Reg	0	0		0.125						54.4
Reg	0	0			0.004					57.2
Reg	0	0				0.019				55.8
Reg	0	0					0.093			54.6
Reg	0	0						0.014	0.107	53.4
Reg	0	0.002	0.011	0.519						57.2
Reg	0.004	0.013	0.385		0.688					57.3
Reg	0	0.002	0.082			0.84				57.1
Reg	0.034	0.004	0.011				0.392			57.4
Reg	0	0.002	0.112					0.917	0.954	57.1
Reg	0.005	0.028	0.561	0.552	0.734					57.4
GLM	0	0	0.003							57.07
GLM	0	0		0.125						54.42
GLM	0	0			0.004					57.21
GLM	0	0				0.049				56.02
GLM	0	0					0.093			54.63
GLM	0	0						0.014	0.107	56.02
GLM	0	0.002	0.011	0.519						57.24
GLM	0.004	0.013	0.685		0.688					57.28
GLM	0	0.002	0.112			0.96				57.1
GLM	0.034	0.004	0.011				0.392			57.37
GLM	0	0.002	0.112					0.917	0.954	57.1
GLM	0.005	0.028	0.561	0.552	0.734					57.43

Table **B-3**: Phase 1 MAWL P values and R-squared Values

Analysis	**Gender**	**Height**	**Leg**	**Torso**	**Weight**	**BMI**	**Body Fat % Scale**	**Category**	**Body Fat % Caliper**	**Norm**	**Over**	**R-Sq**
Reg	0.029	0.064										29.7
Reg	0				0.003							34.6
Reg	0					0.211						27.9
Reg	0						0.02					32.1
Reg	0							0.053				30
Reg	0								0.086			29.2
Reg	0									0.062	0.484	30
Reg	0.025	0.27			0.01							35.7
Reg	0.024	0.051				0.162						31.5
Reg	0.005	0.056					0.016					35.4
Reg	0.027	0.063						0.052				33.2
Reg	0.005	0.047							0.063			32.9
Reg	0.037	0.064								0.062	0.509	33.2
Reg	0.027	0.353			0.03	0.723						35.8
Reg	0.122	0.516			0.465		0.942					35.8
Reg	0.025	0.386			0.087			0.711				35.8
Reg	0.153	0.386			0.073				0.769			35.7
Reg	0.049	0.466			0.057					0.501	0.347	36.5
Reg	0.14	0.612			0.423	0.724	0.906					36
GLM	0.029	0.064										29.68
GLM	0				0.003							34.59
GLM	0					0.211						27.92
GLM	0						0.02					32.07
GLM	0							0.151				30.02
GLM	0								0.086			29.22
GLM	0									0.062	0.484	30.02
GLM	0.025	0.27			0.01							35.65
GLM	0.024	0.051				0.162						31.5
GLM	0.005	0.056					0.016					35.37
GLM	0.037	0.064						0.148				33.22
GLM	0.005	0.047							0.063			32.87
GLM	0.037	0.064								0.062	0.509	33.22
GLM	0.027	0.353			0.03	0.723						35.76
GLM	0.122	0.516			0.465		0.942					35.84
GLM	0.049	0.466			0.057			0.628				36.47
GLM	0.153	0.386			0.073				0.769			35.73
GLM	0.049	0.466			0.057					0.501	0.347	36.47
GLM	0.14	0.612			0.423	0.724	0.906					35.96

Analysis	Gender	Height	Leg	Torso	Weight	BMI	Body Fat % Scale	Category	Body Fat % Caliper	Norm	Over	R-Sq
Reg			0									32.5
Reg				0								37.3
Reg			0.393	0.013								37.9
Reg	0.07		0.465	0.062								40.6
Reg	0.014		0									37.7
Reg		0.037	0									36.3
Reg			0		0.081							35.2
Reg			0			0.866						32.6
Reg			0				0.98					32.6
Reg			0					0.494				33
Reg			0						0.396			33.2
Reg			0							0.642	0.335	34.9
Reg	0.014		0.01		0.081							40.2
Reg	0.061			0.061								40.1
Reg		0.169		0								38.8
Reg				0	0.113							39.3
Reg				0		0.654						37.4
Reg				0			0.791					37.3
Reg				0				0.55				37.6
Reg				0					0.685			37.4
Reg				0						0.623	0.667	38.1
Reg	0.056			0.056	0.104							42.2
GLM	0.07		0.465	0.062								40.56
GLM	0.014		0									37.73
GLM			0					0.267				34.88
GLM			0							0.642	0.335	34.88
GLM		0.421	0.002									38.27
GLM		0.014	0.01	0.081								40.22
GLM	0.061			0								40.14
GLM				0				0.597				38.14
GLM				0						0.623	0.667	38.14
GLM	0.056			0.002	0.104							42.23

Table **B-4**: Phase 2 Leg Average P Values and R-squared Values

Analysis	**Gender**	**Height**	**Weight**	**BMI**	**Body Fat % Scale**	**Body Fat % Caliper**	**Weight**	**Girth**	**R-Sq**
GLM	0	0				0.141			54.6
GLM	0	0.002	0.901			0.212			54.6
GLM	0	0	0.433				0.365	0.89	54.45
GLM	0	0					0.365	0.89	54.32
GLM	0.032	0.442	0.952	0.792	0.875				54.3
GLM	0	0.025	0.824	0.768					54.29
GLM	0	0		0.418					54.28
GLM	0	0			0.417				54.28
GLM	0.033	0.412	0.984		0.839				54.28
GLM	0	0	0.432						54.27
GLM	0	0							54.14
GLM	0		0.025						51.23
GLM	0				0.097				50.71
GLM	0					0.117			50.64
GLM	0			0.126					50.62
GLM	0						0.384	0.895	50.26
Reg	0	0				0.141			54.6
Reg	0	0.002	0.901			0.212			54.6
Reg	0	0	0.433				0.365	0.89	54.5
Reg	0	0	0.432						54.3
Reg	0	0		0.418					54.3
Reg	0	0			0.417				54.3
Reg	0	0					0.365	89	54.3
Reg	0	0.025	0.824	0.768					54.3
Reg	0.033	0.412	0.984		0.839				54.3
Reg	0.032	0.442	0.952	0.792	0.875				54.3
Reg	0	0							54.1
Reg	0		0.025						51.2
Reg	0				0.097				50.7
Reg	0			0.126					50.6
Reg	0					0.117			50.6
Reg	0						0.384	0.895	50.3

Table **B-5**: Phase 2 Torso Average P Values and R-squared Values

Analysis	**Gender**	**Height**	**Weight**	**BMI**	**Body Fat % Scale**	**Body Fat % Caliper**	**Weight**	**Girth**	**R-Sq**
GLM	0	0.003	0.499				0	0	60.8
GLM	0	0.001					0	0	60.71
GLM		0				0.004	0	0	59.83
GLM		0			0.027		0	0	59.18
GLM	0		0.085				0	0	59.16
GLM	0			0.159			0	0	58.97
GLM	0				0.231		0	0	58.86
GLM	0						0	0	58.59
GLM		0					0	0	58.24
GLM						0	0	0	55.12
GLM			0				0	0	54.16
GLM					0		0	0	54.08
GLM	0.011	0.03		0.567					14.92
GLM	0.012	0.042	0.645						14.87
GLM	0.124	0.022				0.695			14.85
GLM	0.047	0.029			0.727				14.84
GLM	0.013	0.021							14.79
GLM	0		0.234						13.23
GLM	0			0.33					13.04
GLM	0.001				0.408				12.94
GLM	0.003					0.637			12.75
Reg	0	0.003	0.499				0	0	60.8
Reg	0	0.002		0.402			0	0	60.8
Reg	0	0.001					0	0	60.7
Reg		0				0.004	0	0	59.8
Reg	0		0.085				0	0	59.2
Reg		0			0.027		0	0	59.2
Reg	0			0.159			0	0	59
Reg	0				0.231		0	0	58.9
Reg	0						0	0	58.6
Reg		0					0	0	58.2
Reg						0	0	0	55.1
Reg			0				0	0	54.2
Reg					0		0	0	54.1
Reg	0.232	0.372	0.646	0.679	0.618				15
Reg	0.012	0.042	0.645						14.9
Reg	0.011	0.03		0.567					14.9
Reg	0.012	0.282	0.997	0.736					14.9

Analysis	**Gender**	**Height**	**Weight**	**BMI**	**Body Fat % Scale**	**Body Fat % Caliper**	**Weight**	**Girth**	**R-Sq**
Reg	0.25	0.333	0.596		0.662				14.9
Reg	0.132	0.068	0.753			0.839			14.9
Reg	0.013	0.021							14.8
Reg	0.047	0.029			0.727				14.8
Reg	0.124	0.022				0.695			14.8
Reg	0		0.234						13.2
Reg	0			0.33					13
Reg	0.001				0.408				12.9
Reg	0.003					0.637			12.7

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