



Effects of spinal supports and training on three dimensional lifting mechanics
by Thomas Scott DeBree

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Industrial and Management Engineering
Montana State University
© Copyright by Thomas Scott DeBree (1995)

Abstract:

A laboratory experiment with 8 male subjects was conducted to examine the role of training and lifting belts during several lifting tasks. The lifting tasks were varied according to lifting frequency and asymmetrical motion. Subjects were asked to lift a 7 kg load 3 times and 9 times per minute. The subjects were also asked to lift with no twist and with a 90 degree twist. The 8 subjects were paired into 2 groups and one of the groups was subjected to a standardized safe lifting training session designed for industrial workers. The subjects were paired based on comparable sitting height measurements. There was found to be no significant difference between the sitting heights of the two groups. Therefore the groups were assumed to be homogeneous with regards to sitting height. The other group served as a “matched” controlled group. Thus, a nested factorial design was specified for observations and data were analyzed using analysis of variance with subject blocks nested under training. Psychophysical, physiological and biomechanical data were collected for each lifting task.

Results indicated that training had a positive impact on lifting style. With training, subjects tended to have a smaller angular displacement at the knee which would correspond to a more bent-knee lift. As well, peak velocities and accelerations at the hips were smaller when subjects were trained indicating that subjects lifted more slowly and smoothly. Trained subjects experienced lower peak accelerations at the left knee also. Because acceleration is directly proportional to force, lower accelerations would result in lower generated forces in related musculoskeletal systems. Overall the positive impact of lifting belts was not as prevalent as training. There was a relationship between lifting belts and right-side mechanics regarding peak velocities. Belts significantly reduced the velocities for this side of the body. The opposite trend was observed with regards to peak acceleration. Peak accelerations were significantly lower for the right side, while belts were used. There may be a number of explanations for why the effect was one-sided. However, further research needs to be done before any concrete conclusions regarding these effects can be made. Frequency in combination with lifting belts was significant at the right hip for both peak angular velocities and accelerations. Subjects without a lifting belt at higher frequencies experienced higher velocities and accelerations at the right hip. Again this effect was observed to be one-sided.

With regards to the physiological and psychophysical variables measured, only training and lifting frequency had a significant effect. It was observed that untrained subjects had higher heart rates. This could be attributed to trained subjects lifting with a generally smoother, slower lifting style. Trained subjects rated the lifts higher on a perceived exertion scale. This could be attributed to the subjects reporting more stress in the upper-leg during a more squat lifting style.

Overall, the results indicate that safe-lift training may provide a positive effect in the very short term. However, the use of industrial lifting belts, either in combination with or independent of a training program, is unjustified since there is no meaningful and consistent reduction in lifting hazards.

**EFFECTS OF SPINAL SUPPORTS AND TRAINING ON THREE
DIMENSIONAL LIFTING MECHANICS**

by

Thomas Scott DeBree

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Industrial and Management Engineering

MONTANA STATE UNIVERSITY - BOZEMAN
Bozeman, Montana

September 1995

N378
D3538

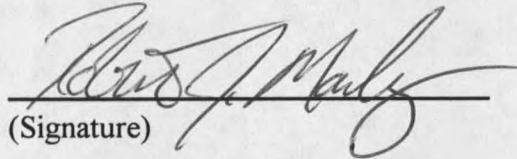
APPROVAL

Of a thesis submitted by

Thomas S. DeBree

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency; and is ready for submission to the College of Graduate Studies.

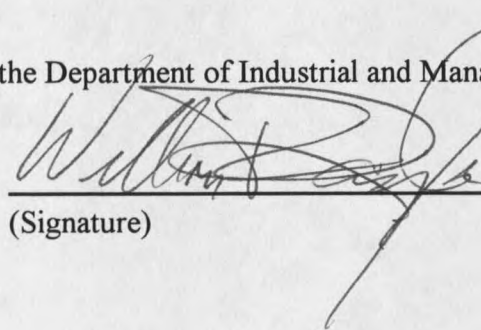
Dr. Robert Marley
Committee Chairperson


(Signature)

9/29/95
(Date)

Approved for the Department of Industrial and Management Engineering

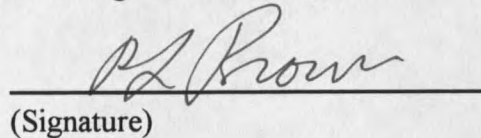
Dr. William Taylor
I&ME Dept. Head


(Signature)

9/29/95
(Date)

Approved for the College of Graduate Studies

Graduate Dean


(Signature)

11/24/95
(Date)

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University - Bozeman, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature

Thomas S. DeBree

Date

10/15/95

TABLE OF CONTENTS

TABLE OF CONTENTS	iv
LIST OF TABLES	vii
ABSTRACT	viii
1.0 INTRODUCTION	1
2.0 LITERATURE REVIEW	2
2.1 Back Support	3
2.2 Epidemiological Research	6
2.3 Biomechanical Research	7
2.3.1 Dynamic Models	8
2.3.2 Intra-abdominal Pressure Measurements	9
2.4 Physiological Research	10
2.5 Psychophysical Research	11
2.6 Experimental Factors	12
2.6.1 Age	12
2.6.2 Strength	12
2.6.3 Gender	13
2.6.4 Body Weight	13
2.6.5 Training	13
2.6.6 Weight of Load	13
2.6.7 Frequency of Lift	14
2.6.8 Height and Range of Lift	14
2.6.9 Container Size	14
2.6.10 Handles	14

2.6.11 Environmental Factors	15
3.0 RATIONALE AND OBJECTIVES	16
4.0 METHODS AND PROCEDURES	18
4.1 Subjects	18
4.2 Apparatus	18
4.3 Experimental Variables	19
4.4 The Task	20
4.5 Physiological Measures	21
4.6 Biomechanical Measures	21
4.7 Psychophysical Measures	22
4.8 Familiarization Period	22
5.0 RESULTS	24
5.1 Descriptive Statistics	24
5.2 Statistical Analysis	25
5.2.1 Kinematic Data	27
5.2.1.1 Angular Position	27
5.2.1.2 Angular Velocity	29
5.2.1.3 Angular Acceleration	33
5.2.2 Physiological Measures	37
5.2.2.1 Blood Pressure	37
5.2.2.2 Heart Rate	40
5.2.3 Psychophysical Measures	41
5.3 General Discussion	42
6.0 CONCLUSIONS	44
6.1 Conclusions	44
6.2 Recommendations for Future Research	44

REFERENCES	46
APPENDICES	53
APPENDIX A: Data Collection Forms	54
APPENDIX A-1: Subject Consent Form	55
APPENDIX A-2: Personal Data Collection Form	57
APPENDIX A-3: Experimental Data Collection Form	58
APPENDIX B: Experimental Data	59
APPENDIX B-1: Kinematic Data	60
APPENDIX B-2: Physiological and Psychophysical Data	64
APPENDIX B-3: Means and Standard Deviations	66
APPENDIX C: Statistical Analysis	68
APPENDIX C-1: Hypothesis Tests on Means	69
APPENDIX C-2: Post-hoc Analysis	70

LIST OF TABLES

Table 4.1: Experimental Variables	20
Table 4.2: Joints included in the link segment model	21
Table 4.3: RPE Scale	22
Table 4.4: Lifting Requirements for Trained Subjects	23
Table 5.1: Summary of Subject Statistics	24
Table 5.2: Sampling Schema	26
Table 5.3: Anova Summary Table for Angular Position at the Left Knee, P_{LK}	27
Table 5.4: Anova Summary Table for Angular Position at the Right Knee, P_{RK}	28
Table 5.5: Anova Summary Table for Angular Velocity at the Left Knee, v_{LK}	29
Table 5.6: Anova Summary Table for Angular Velocity at the Right Knee, v_{RK}	30
Table 5.7: Anova Summary Table for Angular Velocity at the Left Hip, v_{LH}	31
Table 5.8: Anova Summary Table for Angular Velocity at the Right Hip, v_{RH}	32
Table 5.9: Anova Summary Table for Angular Acceleration at the Left Knee, a_{LK}	33
Table 5.10: Anova Summary Table for Angular Acceleration at the Right Knee, a_{RK}	34
Table 5.11: Anova Summary Table for Angular Acceleration at the Left Hip, a_{LH}	35
Table 5.12: Anova Summary Table for Angular Acceleration at the Right Hip, a_{RH}	36
Table 5.13: Anova Summary Table for Systolic Blood Pressure	38
Table 5.14: Anova Summary Table for Diastolic Blood Pressure	39
Table 5.15: Anova Summary Table for Heart Rate	40
Table 5.16: Anova Summary Table for Rate of Perceived Exertion	41
Table 5.17: Summary of Significant Effects	42

ABSTRACT

A laboratory experiment with 8 male subjects was conducted to examine the role of training and lifting belts during several lifting tasks. The lifting tasks were varied according to lifting frequency and asymmetrical motion. Subjects were asked to lift a 7 kg load 3 times and 9 times per minute. The subjects were also asked to lift with no twist and with a 90 degree twist. The 8 subjects were paired into 2 groups and one of the groups was subjected to a standardized safe lifting training session designed for industrial workers. The subjects were paired based on comparable sitting height measurements. There was found to be no significant difference between the sitting heights of the two groups. Therefore the groups were assumed to be homogeneous with regards to sitting height. The other group served as a "matched" controlled group. Thus, a nested factorial design was specified for observations and data were analyzed using analysis of variance with subject blocks nested under training. Psychophysical, physiological and biomechanical data were collected for each lifting task.

Results indicated that training had a positive impact on lifting style. With training, subjects tended to have a smaller angular displacement at the knee which would correspond to a more bent-knee lift. As well, peak velocities and accelerations at the hips were smaller when subjects were trained indicating that subjects lifted more slowly and smoothly. Trained subjects experienced lower peak accelerations at the left knee also. Because acceleration is directly proportional to force, lower accelerations would result in lower generated forces in related musculoskeletal systems. Overall the positive impact of lifting belts was not as prevalent as training. There was a relationship between lifting belts and right-side mechanics regarding peak velocities. Belts significantly reduced the velocities for this side of the body. The opposite trend was observed with regards to peak acceleration. Peak accelerations were significantly lower for the right side, while belts were used. There may be a number of explanations for why the effect was one-sided. However, further research needs to be done before any concrete conclusions regarding these effects can be made. Frequency in combination with lifting belts was significant at the right hip for both peak angular velocities and accelerations. Subjects without a lifting belt at higher frequencies experienced higher velocities and accelerations at the right hip. Again this effect was observed to be one-sided.

With regards to the physiological and psychophysical variables measured, only training and lifting frequency had a significant effect. It was observed that untrained subjects had higher heart rates. This could be attributed to trained subjects lifting with a generally smoother, slower lifting style. Trained subjects rated the lifts higher on a perceived exertion scale. This could be attributed to the subjects reporting more stress in the upper-leg during a more squat lifting style.

Overall, the results indicate that safe-lift training may provide a positive effect in the very short term. However, the use of industrial lifting belts, either in combination with or independent of a training program, is unjustified since there is no meaningful and consistent reduction in lifting hazards.

1.0 INTRODUCTION

The requirements in the work place have undergone a large number of changes since the industrial revolution. Machines, now, more than ever, have been developed and utilized to save time and effort. Unfortunately, machines are unable to perform every task. For this reason, workers can still be required to lift and handle materials in the performance of their jobs. The reality is that raw materials must be moved during work processes. These moving tasks can include lifting, lowering, pulling, holding, and carrying activities. These types of activities have been long recognized as potentially hazardous. Of these activities, lifting tasks can be considered to be among the most dangerous. A study conducted by National Institute for Occupational Health and Safety, NIOSH, indicated that a majority of all material handling related injuries were related to lifting operations [NIOSH 1981].

A major focal point of lifting injuries in the body is the lower back. That particular portion of the body receives stresses more likely to cause damage than any other joint involved in a lift [Rowe 1969; and Ayoub, et al. 1978]. This can be seen in the number of financial claims billed against this form of injury. Back injuries account for an estimated 35% of all compensation claims [Taber 1982]. It has been further reported that 48.1% of all worker compensation claims were initiated as a result of lower back pain caused through lifting [Klein, et al. 1984]. The costs associated with these claims reached an estimated 14 billion dollars in direct financial compensations in 1982 [Taber 1982]. However, the actual cost may be much higher. Studies have indicated that indirect costs of a lower back injury may be as much as four times higher than the direct cost [Asfour, et al. 1983].

The immense costs involved provide a powerful incentive to reduce incidence of lower back injuries in industry. The question is whether current approaches relieve any of the risks associated with the manual material handling activity. Fully understanding risk reducing agents is an important component in reducing the incidence of lower back injuries. This paper will analyze the use of lifting corsets and lifting motions in order to improve knowledge regarding the effectiveness of ergonomic corsets and training.

2.0 LITERATURE REVIEW

Lifting activities have been identified as major health hazards in industrial settings. Lower back pain is perhaps the largest malady associated with a lifting task. The costs associated with back injuries are extremely high and it is important that as many of these injuries be avoided as possible. Even with this knowledge, back injuries still occur at an alarming frequency [Ayoub 1992]. Nearly every industrialized country suffers from occurrences of back injuries in their industries. In the United Kingdom, spinal and trunk injuries comprise 19% of all reported injury incidences [Troup 1965]. In Scandinavian countries, it has been found that 50% to 80% of all workers will at some time have back pain related complaints and that back problems comprise 9% to 19.5% of all worker absences [Svensson, et al. 1982].

Similar occurrences have appeared in the United States. Approximately 35% of all compensation claims are related to back injuries [NSC 1983]. These claims account for over 25 million lost work days [NIOSH 1981] and an estimated 14 billion dollars in direct costs [Taber 1982]. Statistics based on claims filed indicates that lifting appears to be the largest contributor to lower back pain. Roughly 48% of all back pain claims are related to lifting tasks [Klein, et al. 1984]. One study found that next to headaches, back pain is the most prevalent problem reported [Khalil, et al. 1984].

In light of the many problems associated with lifting, it would seem obvious that lifting tasks need to be studied. Results from studies done on this topic would be important to practitioners in many disciplines [Marley 1987]. Ultimately, the result of these studies can be paired with three traditional approaches used to reduce the severity and number of over-exertion injuries caused by lifting tasks. These three approaches are:

1. selective screening of workers for differing tasks,
2. proper training in safe lifting techniques, and
3. designing tasks that comply with the capabilities of the workers.

Developing larger knowledge bases on lifting factors will aid a manager in applying these approaches. The goal is to govern lifting tasks according to safe and permissible lifting capacities.

There are four basic areas of study that can be used to examine lifting activities. These are the scientific approaches used in nearly all ergonomic studies. The approaches, as outlined by the National Institute for Occupational Safety and Health [NIOSH 1982] are:

1. the Epidemiological approach,
2. the Biomechanical approach,
3. the Physiological approach, and
4. the Psychophysical approach.

The remainder of this chapter will review research conducted in these areas that relates to lower back injuries. Also of interest, is the use of training and ergonomic corsets as tools to reduce the risk of lower back injuries. The chapter will first present research related to back belts and the research approaches used. Next the experimental factors that are important in research of this nature will be reviewed.

2.1 Back Support

Spinal supports have historically been used to reduce lower back pain. Recent rationale for their application is that a back support raises the intra-abdominal pressure which provides stability to the back and reduces pain [Kumar, et al. 1986]. The application of orthotic devices is employed for three reasons. First, the device provides support for the segment as well as immobilizing the area. Secondly, support helps to correct or prevent deformity in the body segment. Finally, the support helps to restore function to the body segment [Jordan 1963]. Pain is usually present and in clinical practice it has been observed that, despite incomplete immobilization, low back bracing generally results in symptomatic reduction of pain. Partial immobilization and support to the lumbar region are the two likely factors leading to relief [Kumar, et al. 1986]. A significant mechanical support to the spine is provided by the raised intra-abdominal

pressure [Bartelink 1957; Davis 1964; and Morris, et al. 1964]. The support is generated by forcing the abdomen to tense. The phenomenon has been variously assigned to reflex [Bartelink 1957] or conditioned reflex activities. Whether or not this reflex actually exists is opened to conjecture. Currently, there is no identifiable neuro-pathway associated with the reflex [Kumar, et al. 1973].

Anatomically, it has been suggested that the transverse abdominous belongs to the same group as the diaphragm and the transverse thoracic muscle. These muscles together with the pelvic floor surround the abdominal cavity, and by their coordinated contraction, create a high pressure anterior to the spine. This high pressure "balloon" has a force vector which acts parallel to the spine in the upward direction on the anterior side. This force tends to resist flexion and assist extension of the spine. It acts on a long lever arm, relative to the extensors of the spine and is of greater magnitude during initiation of extensor movement [Kumar, et al. 1986]. The described support has been calculated by Morris, Lucas, and Bresler (1961) to reduce 30% of compression stress at the lumbosacral junction, a frequent site of low back pain. This leads to a conclusion that most low back pain patients have weak abdominal muscles [Hemborg, et al. 1985]. Therefore strengthening these muscles should reduce the forces in the lumbosacral junction and consequently reduce the risk of pain and injury. It is suggested that back supports are one means of artificially strengthening the effect of these muscles because of the increase of abdominal pressure that results [Kumar, et al. 1986].

It has been shown that wearing a belt has effectively increased the abdominal pressures [McGill, et al. 1990; Harman, et al. 1989]. McGill, et al., (1990) speculated that this could be attributed to their subjects handling loads 10 times heavier than normal which produced intra-abdominal pressure 2 to 3 times higher.

Hermong, Moritz, and Lowing (1985) demonstrated a decrement in the electromyography (EMG) activity of the erector spinae with elevated intra-abdominal pressure conditions. McGill, et al., (1990) reported that wearing an ergogenic corset resulted in lower abdominal EMG activity when compared with lifting belts. The development of this conclusion was difficult, however, because of the limited information.

It has also been speculated that the use of an ergonomic corset will hinder axial twisting resulting in safer pivoting through moving the feet. Avoiding twisting situations has been advocated by industry safety associations, such as NIOSH, as a means to reduce over-exertion injury. It is also believed that a belt will help to support the anterior shear loads generated when the pelvis inclines forward of the trunk. While the rib cage and the pelvis are rigid structures and consequently better equipped to support shear forces, the abdomen is not as rigid and could benefit from additional support.

Kumar and Godfrey (1986) theorized that different belts will immobilize the target area differently. As a result, different belts will likely have differing physiological costs associated with wearing the belt. Therefore, the choice of spinal support should be based on criterion other than abdominal support.

It has also been shown that back belts can significantly reduce the time to onset of an initial injury [Asundi, et al. 1993]. This does not mean that the belts will be effective in preventing injury. It is only believed that they can prolong the time it takes for an injury to occur. However, it is believed that the use of a belt will improve the chances of the wearer avoiding injury over not using a belt. This theory is based on a back belt acting over a period rather than at the instant of injury. As a result, the validity of this theory is debatable. It is also believed that the belt may relieve existing back pain and consequently improve the performance of a worker who is already injured.

The actual effectiveness of back belts has also been shown to be less than useful. Duggasani showed that the use of a back belt did not significantly reduce the risk of injury or relieve pain [Duggasani 1994]. This conclusion was based on lifting data analyzed according to biomechanical and physiological parameters. The study showed that the use of a lifting belt did not significantly impact the lifting style of a subject. It was also found that the physiological parameters of the subject were not different except for the individual's blood pressure. A person wearing a belt was seen to have a higher blood pressure. Furthermore, there was also no psychophysical difference found in wearing a belt over not wearing one. This leads to the conclusion that the use of a belt may be nothing more than a placebo and it may even be dangerous for individuals with high blood pressure. The belts may also lead the wearer to retain a false sense of security [Rys, et al.

1994]. Rys and Konz (1994) further concluded that the use of belts may weaken the subject. As a result, when the belt is removed the likelihood of an injury will increase. There also appears to be comfort problems associated with the use and wear of lifting belts.

Other research indicated that use of a lifting belt by itself is not advisable. The use of a back support should always be accompanied by a general program covering the general biomechanics of the back [Genaidy, et al. 1995]. It is also strongly recommended that job-simulated exercise programs be used to improve strength, endurance, and flexibility. This leads to the question of whether belts are currently used in combination with training. If this is the case, the role of training needs to be determined before the effectiveness of lifting belts can be fully known.

2.2 Epidemiological Research

Webster's Dictionary defines Epidemiology as the branch of medical sciences that deals with the incidence, distribution, and control of disease in a population. This can be related to lower back pain through the identification of incidences and distribution of injuries for a given population. In addition, possible means to control the incidence of injury will need to be identified. The effects that can influence injury can be divided into work related factors and personal factors [Marley 1987]. Work related effects deal with factors such as weight and size of loads, while personal factors deal with factors such as gender and level of training.

Conducting a thorough epidemiological study can be very time consuming. The study requires the collection of data over a large population. The time involved and the costs associated with injury profiles collected during the study over a large number of subjects tend to make this method impractical for most studies. Furthermore, it is difficult to identify the environment responsible for the injury. Inclusion of factors that occur outside the work place are often not possible. As a result, the true relationship between lifting tasks and health problems may never be fully understood.

Studies have revealed some interesting information related to the use of lifting belts. Long-term use of lifting belts may decrease abdominal muscle tone and thereby increase the likelihood of injury if the influence of the belt is removed [NIOSH 1994]. These conclusions are based on data that is inconclusive and still needs to be developed, however.

2.3 Biomechanical Research

Based on biomechanical data, NIOSH has concluded that there is significant data available to indicate that lifting belts reduce biomechanical loading of the trunk during lifting activities [NIOSH 1994]. There are some claims that the belts restrict spinal motion which is beneficial because it diminishes the torques generated in the lower back. NIOSH stresses, however, that the data behind this conclusion is inconclusive and the need for more research still exists.

The biomechanical approach involves the use of the laws of physics and various engineering concepts, to describe body motions undergone during normal activities [Franked, et al. 1980]. The approach attempts to determine forces imposed on the musculoskeletal system during an activity. The approach is considered to be appropriate for predicting the maximal lifting capacity of an individual given a low lifting frequency [Smith 1980]. This approach and many current analysis techniques are not able to deal with high speed turnover activities. The forces that a biomechanical model will calculate include the reaction forces and torques at the joints of interest. In addition, the compression and shear forces imposed on the lower back as a result of lifting can be determined [Ayoub, et al. 1983].

Biomechanical models have determined that any acceptable load limit for a lift is a function of back strength. This conclusion highlights the back as the primary agent involved in performing a lift. Furthermore, it identifies joints in the back where injuries are most likely to occur. The most recognized location for a back injury to originate as a result of compressive force is the lumbar region, in particular the L5/S1 segment [Garg 1979]. Building on this point, compressive force has been used as a criterion for determining lifting limits. One study has identified a compressive force limit of 650 kg

[Chaffin, et al. 1973]. Subsequently, NIOSH has adopted this value in developing a maximum permissible limit (MPL) value for loads involved in a lifting activity [NIOSH 1981]. However, selecting single weight limits can be misleading. Data indicates that there is a large variation in the compressive strength of the L5/S1 segment. As a result, more expansive data bases containing distributions of compressive forces for lumbar vertebral segments during lifting tasks for both genders are required [Ayoub 1992].

Another study identified 3400 newtons of spinal disc compression force as a minimum allowable weight of lift (MAWL) limit [Park, et al. 1974]. The study also evaluated whether existing published MAWL values represent safe physiological lifting limits. The study concluded that 75% to 90% of all MAWL are often used as a threshold of risk. As a result, the MAWL represents forces that, in most cases, are too great to protect a male population when performing infrequent lifting tasks. The study admits, however, the need for further study.

In order to address the need for further research, it is necessary that the construction of static and dynamic biomechanical models be understood. Models of a dynamic nature are generally more useful for modeling tasks that require high repeatability and potentially quick motions. For this reason, only dynamic models will be evaluated.

2.3.1 Dynamic Models:

Dynamic models function under the assumption that the segments of the body are under constant motion during an activity. Therefore, forces are analyzed at various stages during a lifting activity as a function of time. Models have been developed that calculate these forces. One such model is able to calculate the compressive and shear forces at the L4/L5 and L5/S1 joints during a lifting task [El-Bassoussi, 1974]. The model was based on analyzing a subject lifting a variable weight to a height of 30 inches.

The model emphasizes the differences between leg lifts and back lifts. The results of the model showed that the back experienced higher compressive forces during a back lift. Park and Chaffin (1974) used this model to study a straight back/bent knee lifting position vs. a back lift. Based on the results, they recommended that a straight back/bent knee lifting position is preferable to a straight back lift.

Another model involved the development of a non-linear programming model [Muth, et al. 1978]. The model employed anthropometric measurements, size and weight of the object lifted, starting and ending points, and time performance as constraints for the model. The function that was minimized was the integral of the square of the ankle torque function. This function included the torques occurring at the other joints. The study showed that the time to perform a task was a critical component in the model.

A large number of biomechanical techniques have been developed. One model that has a direct correlation to the use of a back belt is the measure of intra-abdominal pressure measurements. It is hypothesized that belts increase intra-abdominal pressure which in turn provide greater support to the spine.

2.3.2 Intra-abdominal Pressure Measurements:

In the 1920's, it was asserted that pressures within the trunk might assist with its mechanical efficiency [Kieth 1929]. The assertion is based on the thought that a flexion moment develops about the spine when a weight is lifted. This moment is counter balanced by the posterior back muscles. The pressure in the trunk cavity can further counter balance the moment through the production of an extension moment. As a result, the muscle contraction forces needed for equilibrium are reduced and the stress on the vertebral column is reduced [Park, et al. 1974]. Studies have confirmed that the intragastric pressure increased when the trunk moment was increased [Davis 1956; Bartelink 1957]. Further studies have shown that load on the spine is reduced by 30% because of the support originating from the pressures within the trunk.

The resulting relationship between the trunk moment and increasing pressures lead to the conclusion that intragastric pressure can be measured in order to assess loads during a lifting task [Park, et al. 1974]. Working from this knowledge, other studies have shown that peak pressures of 100 mm of mercury within the spine will lead to higher instances of reported back injury [Davis, et al. 1979].

Measuring intra-abdominal pressures is a simple and safe operation. Furthermore, data handling tends to be simple because a single value or curve tends to emerge. However, there are concerns associated with this technique. The chief concern is the

uncertainty associated with the relationship between pressure and spine compression. All of the studies to date have exhibited a deficiency. The abdominal pressure rises in parallel with the load over a force range, provided that the system is static and the position is symmetrical. The deficiency in the literature arises from the influences generated by the relationships between asymmetrical loads and postures. Furthermore, the pressure responses are not continuous. Another problem stems from uncertain knowledge of how well intragastric and intra-intestinal pressure measurements actually reflect the true intraperitoneal pressure [Park, et al. 1974].

When a lift is initiated, the intra-abdominal pressure is assumed to yield its major support to the spine when the trunk moment is at its maximum. This does not seem to be the case. It is uncertain how much abdominal muscles relieve the spine. When the relief occurs is also uncertain [Park, et. al. 1974]. The use of this method is not always advisable as a result.

2.4 Physiological Research

The physiological approach is considered to be a complement to the biomechanical approach. Where the biomechanical approach is considered to be effective for low frequency lifts, the physiological approach is more appropriate with higher frequencies. The approach focuses on physiological stresses imposed on the body during a task. Physiological models are primarily applied to repetitive lifting where it is presumed that the lifting load is well within the maximal physical strength of the subject. The oxygen transport system is the key limiting factor impacting these lifting tasks.

Various dependent measures may be used in a Physiological model. Some measures that may be of interest can include oxygen consumption, heart rate, pulmonary ventilation, energy expenditure, blood pressure, and percent of physical work capacity (PWC). Certain studies have indicated that there are only three primary physiological measures for dynamic activities that should be employed [Snook, et al. 1967; Ayoub, et al. 1978]. The three measures are oxygen consumption, heart rate, and energy expenditure.

The physiological approach takes a very different view of a lifting task compared to the biomechanical approach. For instance, studies have shown that the bent

knee/straight back position for lifting is more physiologically stressful than the straight back lifting method [Brown 1971; Garg, et al. 1979]. This can be attributed to the greater volume of muscles involved in the straight back/bent knee lift. As a result, heavy loads will require more energy with the straight back/bent knee method [Das 1951; Asfour 1980].

A subject's heart rate is an important physiological measure. It has been found that 115 beats per minute (bpm) should not be exceeded when heart rate is used as a criteria for energy expenditure [Brouha 1967]. Another study indicated an allowable range of 110 to 130 bpm not be exceeded for continuous work activities [Snook, et al. 1967]. This same study recommended that 112 bpm for leg tasks and 99 bpm for arm tasks were optimal.

The effect of the load lifted, lift frequency, the vertical height of the lift, and the container size has also been studied [Mital 1980]. The study noted that oxygen consumption and heart rate increased in a linear relationship to these variables. It was also found that the presence of handles for the container slightly reduced the oxygen consumption for the task.

Bakken (1983) found that an interaction exists between range of lift and frequency of the lift. It was also found that this interaction coupled with range and frequency separately had a significant effect upon heart rate during a task. This leads to the conclusion that variations in heart rate can be used as an indicator of worker capability with regards to range and frequency.

2.5 Psychophysical Research

The psychophysical approach involves analyzing a subject's perception of a physical stimuli, such as a lifting task. Lifting capacity would be determined based on a subject quantifying his tolerance to the lifting task [Ayoub 1987]. This is accomplished by assigning subjective qualifiers to numerical values. For example, if a lift was deemed to be very difficult, the subject may score the lift an 8 on a scale of 1 to 10.

A subject's evaluation of the discomfort associated with lifting belts has been studied. It has been found that body part discomfort did not vary significantly with the use

of a lifting belt [Contreras, et al. 1995]. Body part discomfort did seem to increase over time, however. Therefore, there is some question regarding the extended use of lifting belts to reduce pain.

To date, only a limited amount of research has been collected to assess the perception of acceptable lifting loads while using lifting belts [NIOSH 1994]. Available data have suggested that subjects are able to lift heavier loads while using a belt. This may be attributed to the subject's perception of the task improving because of the attention given to them by the individuals conducting the experiment. This effect is commonly referred to as the "Hawthorne Effect." In general, the need to collect more data regarding the perception of lifting limits while using belts still exists.

2.6 Experimental Factors

There are several individual and task factors that can have an effect on lifting capacity. The chief individual factors of interest are the subject's age, strength, gender, and body weight in addition to how well the subject has been trained. The American Industrial Hygiene Association (1970) has identified weight of lift, frequency of lift, height and range of lift, and container size as significant task oriented factors.

2.6.1 Age

It is well documented that physiological parameters decrease with age [Astrand, et al., 1977]. It has been reported that individuals over the age of 65 have a PWC of 70% lower than a 25-year-old individual. Other research has shown the opposite to be true as well. Muller (1962) showed that for submaximal loads, VO_2 max was unaffected by age.

2.6.2 Strength

The maximal strength of a subject will vary from subject to subject. It has generally been seen that maximal strength for an individual will be realized between 20 and 30 years of age. At age 65 it has been seen that this maximal strength will degrade to a level 80% of the maximal strength between 20 and 30 [Astrand, et al. 1977]. However,

the maximal acceptable weight of a lift is unaffected by the variance caused by age [Ayoub, et al., 1978]. With respect to gender, the female has been observed to have a maximal strength that is 60% of a male's maximal strength at the same age.

2.6.3 Gender

There exists several significant differences between males and females regarding anthropometrics, mean heart rate, and risk of injury [Herrin, et al. 1974; and Garg 1976]. Researchers have claimed that female lifting strength is 60% of males [Asmussen, et al. 1962; and Snook, et al. 1974].

2.6.4 Body Weight

There is a linear relationship between body weight and energy expenditure in men [Asfour 1980]. Increases in body weight results in increases for energy usage. The relationship holds true for women, but the slope is reduced [NIOSH 1981].

2.6.5 Training

In general, improvements of PWC values can be expected as a result of training. Astrand and Rodahl (1977) stated that regular training increased individual PWC, in most cases, by 10% to 20%. Ready and Quinney (1982) documented the effects of training and de-training of subjects. They found that there will be a 36% increase in PWC after 9 weeks of training. PWC was conversely found to decrease by 11% after a 9 week de-training period. It has also been shown that there is a tendency to lift more quickly and to shift moments to the stronger muscles during the process of learning lifting patterns [Fogleman, , et al. 1995]

2.6.6 Weight of Load

Increased load weight will result in increased metabolic energy demands for a worker. This is a well documented assumption and is very intuitive [Frederick 1959; Mital 1980; and Asfour 1980].

2.6.7 Frequency of Lift

Lifting capacity will decrease as lifting frequency is increased [Snook 1967; Bakken 1983]. Furthermore, increased physiological responses have been found to correspond with increased frequency [Aquilano 1968; Hamilton, et al. 1969; and Mital 1980].

2.6.8 Height and Range of Lift

Mechanical work has been shown to be proportional to height of lift. As a result, energy expenditure will increase with increases in vertical height [NIOSH 1981]. This is based on the following formula:

$$\text{Mechanical Work} = \text{Load} * \text{Frequency} * \text{Height of Lift.}$$

Aquilino (1968) and Garg (1976) observed that lifting capacity was more dependent on the range of height. This relies on the muscle group used and the varying energy expenditures associated with these muscles. Since the squat lift involves more muscle mass, Snook (1978) and Ayoub, et al., (1978) asserted that the maximum acceptable weight of lift was higher in the floor to knuckle lift.

2.6.9 Container Size

Ayoub, et al., (1978) concluded that the amount of weight lifted was inversely proportional to the container size in the sagittal plane when related to psychophysical parameters. Other studies have developed similar conclusions [Martin, et al. 1972; Asfour 1980].

2.6.10 Handles

Garg and Saxena (1979) concluded that the maximum acceptable weight of lift for containers with handles was greater than for those without handles. Appropriate handles facilitate reduced risk of injury [Mital 1980].

2.6.11 Environmental Factors

Factors most affecting physiological responses in workers are temperature, humidity, air circulation, and atmospheric constituents [Brouha 1967]. Heart rate increases approximately 7 to 10 bpm for every 10 degree (Celsius) rise in ambient temperature [Kamon, et al. 1971].

3.0 RATIONALE AND OBJECTIVES

The lifting capacity of a worker can be affected by a number of factors. These factors have been found to include age, gender, body composition, the environment, PWC, and the task parameters. These all influence the ability of an individual to perform a repetitive task.

Various approaches have been utilized to reduce the risk of injury due to over lifting. One approach that has gained wide spread usage in recent years is ergonomic corsets. The belts are believed to reduce the risk of injury and in some cases to relieve pain resulting from a lifting task. The validity of these belts has come under some scrutiny. This paper will focus on the effectiveness of these belts.

Researchers showed that wearing a lifting belt results in higher intra-abdominal pressure [McGill, et al., 1990; Harman, et al., 1989]. The use of intra-abdominal pressure to develop safe levels of manual lifting is debatable. Some researchers believe that the belts are useful in a role as a reminder. The belts remind the worker to lift properly and there is some belief that the belts are tied to management concern which also helps to remind the worker to lift properly. Another problem is that the use of a lifting belt is almost always accompanied with training. Therefore it may be difficult to divorce the impacts caused by these two effects on the nature of a lifting task.

The feelings about corsets in industry is mixed. Some feel very strongly that the belts are an effective means to reduce the risk of injury while others believe the belts are of no significant value. Few studies have adequately collected psychophysical parameters on the worker's perceived exertions with lifting belts. As a result, it is important to expand the knowledge base on psychophysical parameters related to the corset's role in lifting tasks in industry.

Researchers on this subject are divided as well. Some have shown that they can be useful and some have identified their inability to favorably impact the worker. The data is far from complete. Overall, there have been few systematic investigations into the effects of corsets and their interaction with the major lifting conditions of frequency and load. To

date, only Duggasani (1994) has conducted any specific research into this area. It is the objective of this research to expand on the initial work performed by Duggasani as well as address the points stated earlier. Therefore the objectives of this study were:

1. To Build on the knowledge developed by Duggasani's research by expanding the analysis into three dimensions and by including a training effect.
2. To document and analyze major biomechanical parameters during controlled lifting activities for the impact caused by a corset and training. The major factors of interest include:
 - i. Angular positions of the knees at the lift origin,
 - ii. Maximal angular velocities at the knee and hip joints, and
 - iii. Maximal angular accelerations at the knee and hip joints.
3. To document and analyze major psychophysical and physiological parameters during controlled lifting activities for the impact caused by a corset and training. The major factors of interest include:
 - i. Ratings of perceived exertion,
 - ii. Blood pressure levels (both systolic and diastolic), and
 - iii. Heart rate.
4. To develop recommendations about the effectiveness of both training and ergonomic corsets during lifting activities.

4.0 METHODS AND PROCEDURES

4.1 Subjects

Eight male subjects were selected from the student population at Montana State University. Students were selected for two reasons because of their flexible schedules and the high concentration of homogenous age groups present in the population.

Subjects were screened in order to eliminate potential subjects who have a history of heart disease or lower back problems. The screening process was accomplished through the use of a questionnaire. The students were further screened based on heart rate and blood pressure measurements. Subjects with resting heart rates greater than 95 or with resting blood pressure greater than 150/90 were excluded from the study.

The subjects were then paired together based on a measure of each subject's sitting height. The sitting heights of the eight subjects were listed in order from the tallest to the shortest and the subjects paired into two groups. This was accomplished by randomly assigning the tallest subject to one of the two groups and the next tallest subject to the other. This process continued with the next two subjects and so on until all eight subjects had been assigned. The goal was to have two homogenous groups of subjects based on anthropometric measures. Therefore, one group could be trained and the other group allowed to lift freely because the physical attributes of both groups were equivalent. Sitting height was used to pair the subjects because of the close correlation between the trunk and the lower back. Subjects were then asked to sign the consent form contained in Appendix A prior to beginning the experiment.

4.2 Apparatus

Two video cameras were used to record lifting motions of subjects in three dimensions. The video footage was used in conjunction with the Ariel Performance Analysis System (APAS). The video footage was captured by the APAS to determine

angular motion values for key joints involved in the lift. Digitized data were smoothed using the cubic spline transformation. The four joints of chief interest were the two hip and two knee joints. The angular activity at these joints was evaluated for changes. Motions at these joints are important because they can be equated to the lifting style of the subject and can be used to evaluate the impact of various factors on the subject's ability to lift.

The heart rate and blood pressure of the subject were collected with a SD-700A Blood Pressure Monitor (IBS Corporation). The readings were taken after each trial with the subject in a seated position.

The ergonomic corset used for this experiment was a belt made by Proflex. The container that was lifted in the experiment was made by Rubbermaid. The container was a plastic storage unit with preformed hand-holds, 21 inches long by 15 inches wide by 9 inches deep. The weight of the container was adjusted by lead shot to reach the desired weight.

4.3 Experimental Variables

A summary of the independent, dependent, and controlled variables that comprise the experimental model is included in Table 4.1.

Table 4.1: Experimental Variables

Variable Class	Variables
Independent	Lifting Frequency (3 and 9 lifts/min) Assymetry (0 and 90 degrees twist) Ergogenic Corset (with and without) Training (with and without)
Dependent	Physiological: Heart Rate Blood Pressure Biomechanical: Joint Angular Displacements at Origin Joint Peak Angular Velocities Joint Peak Angular Accelerations Rate of Perceived Exertion
Controlled	Population Height of Lift (shoulder height) Lifting Load (7 kg)

4.4 The Task

The experiment began after the subject had been properly positioned for the two video camera views. The subject was required to lift a fixed mass, 7 kg, at a variable frequency, 3 lifts/minute and 9 lifts/minute, for a six - minute duration. Subjects were required to perform a lifting task with and without a lifting belt. The heart rate and the blood pressure of the subject were monitored upon completion of the task. The subject was continuously filmed during the final two minutes of the task. The filming period corresponds to the period when the subject has reached a steady-state condition for the activity. After the six - minute task had been completed, the subject was requested to provide a rating of perceived exertion for the task. All of the data were collected with the aid of the data collection forms contained in Appendix A.

4.5 Physiological Measures

The resting measures of heart rate and blood pressure were recorded for each individual included in the experiment. The resting values were recorded at the conclusion of a ten-minute interval of the subject sitting upright in a chair. These same measures are the same parameters that were of interest during the experiment. They were collected with the aid of the apparatus identified earlier. The blood pressure and heart rate values were collected at the conclusion of each lifting task.

4.6 Biomechanical Measures

A randomly selected lift during the filmed period of the task was captured for each task from the video footage and digitized with the APAS motion analysis system. A twelve point link segment model was used. The twelve body landmarks that define the link segments in the model are given in Table 4.2. Parameters of interest were determined for the limb connector joints at the knees and hips. The resulting data was analyzed to identify changes in lifting styles from task to task.

Table 4.2: Joints included in the link segment model.

Joint #	Joint Locations	Description
1,2	Ankles	Joint angle generated between the top of the foot and lower leg
3,4	Knees	Joint angle generated between the upper and lower legs
5,6	Hips	Joint angle generated between the upper leg and the trunk
7,8	Shoulders	Joint angle generated between the upper arm and the trunk
9,10	Elbows	Joint angle generated between the upper and lower arm
11,12	Wrists	Joint angle generated between the hands and the lower arm

4.7 Psychophysical Measures

At the completion of each lifting task, each subject was asked to rate the experience. The rating was based on a 6 to 20-point scale given in Table 4.3. The selected value indicated the exertion that the subject psychologically associated with the task.

Table 4.3: RPE Scale

6	Very Light	14	
7		15	Slightly Strenuous
8	Light	16	
9		17	
10		18	Strenuous
11	Slightly Moderate	19	
12		20	Very Strenuous
13	Moderate		

4.8 Familiarization Period

Prior to the experiment, two forms of familiarization were provided. The first involved acquainting the subject with the equipment and the required tasks. This included connecting the subject to the heart rate monitor and obtaining a blood pressure reading. The second involved a training procedure used to identify the proper lifting techniques required of the subject. This was accomplished by having the subject watch a brief video on proper lifting techniques. The video that was selected for this purpose was "Working Out At Work: In Business and Industry", by Educational Opportunities, a Saunders Group Co. Only half of the subject pool was required to view the video. The information contained in the video was reinforced during a task by having Table 4.3 made visible during the lift and monitoring the subject for proper lifting technique. After watching the video, the subject was then acquainted with the equipment and the task.

Table 4.4: Lifting requirements for trained subjects.

- 1 Keep back slightly arched during the lift.
 - 2 Keep head aligned with the back during the lift.
 - 3 Keep the load being lifted close to the body.
 - 4 Lift the load primarily with the legs, not the back.
 - 5 When lifting with a belt, push into the belt with abdomen while lifting.
-
-

5.0 RESULTS

The data collected in this experiment and the relevant analysis are presented in this chapter. The analysis of variance was conducted with the aid of a statistical package, SYSTAT (SYSTAT, Inc., 1990). The raw data for the kinematic, physiological, and psychophysical measurements are contained in Appendix B. The chapter is partitioned into four sections. The first section reviews the descriptive statistics for the subjects used in the experiment. The second section reviews the kinematic data collected in the experiment. The third section reviews the physiological data collected and the last section reviews the psychophysical data collected.

5.1 Descriptive Statistics

Table 5.1 presents a summary of the 8 male subjects who participated in this study. The data include the anthropometric and physiological measures taken from each subject.

Table 5.1: Summary of subject statistics.

Variable	Mean	Std. Dev.	Range
Age (Years)	23.50	2.50	21.0 - 28.0
Weight (Kg)	81.00	12.28	60.0 - 100.0
Stature (cm)	171.90	4.32	169.2 - 180.8
Sitting Height (cm)	91.00	2.80	86.5 - 94.5
Leg Length (cm)	83.60	3.34	79.2 - 89.5
Arm Length (cm)	58.50	15.14	54.5 - 99.9
Resting Heart Rate (bpm)	67.00	10.40	53.0 - 85.0
Resting Systolic Blood Pressure (mm of Hg)	123.00	22.51	76.0 - 153.0
Resting Diastolic Blood Pressure (mm of Hg)	69.00	11.97	55.0 - 90.0

The sample means for the anthropometric link measures were assumed to come from the U.S. population with average measurements reported in Fitting the Task to the Man

(Grandjean 1988). The measurements from a link segment model were subjected to a hypothesis test for one mean. The results indicated that the population from which the subjects were drawn had significantly smaller arm and leg lengths compared to the US population. Sitting height was found to not be significantly different from the national average. Sitting height was also subjected to a paired t-test for the pairs of subjects assigned to each treatment group. It was found that there was no significant difference between the means pairs. Thus, the treatment were considered homogeneous with respect to this criterion. The calculations used for these tests are contained in Appendix C.

5.2 Statistical Analysis

A nested factorial design was used to perform the statistical analysis. Subjects were nested under training because it was impractical to completely randomize the experiment with a technique like a Latin Square. Therefore, the subjects were paired into two groups for the training effect and only the lifting conditions were completely randomized. The analysis was completed with the SYSTAT computer software package using the MGLH routine. The following is the model that was used:

$$Y = S_{j(i)} + T_i + A_k + C_l + F_m + TA_{jk} + TC_{il} + TF_{im} + AC_{kl} + AF_{km} + CF_{lm} + TAC_{ikl} + TAF_{ikm} + ACF_{klm} + TCF_{ilm} + E_{n(jklm)}$$

Where, S = Subject block, nested within Training effect,
 T = Training effect,
 A = Ayssemetry effect,
 C = Corset effect, and
 F = Lift frequency effect.

Subjects were treated as a block in this analysis, although treatment as a random effect was an alternative. Some of the information provided by the block was random because of the natural variation between human subjects. However, some randomness was reduced by pairing the subjects into two groups. Pairing into two groups was based on

sitting height, because the trunk dimension is an important segment for gauging reactions in the lower back. The subject's sitting heights were all measured and subjects with like heights were paired. Thus, the manner by which subjects were paired diminished randomness within the subject block.

Nonetheless, the choice of which group the subject would belong, trained or not trained, was random. Furthermore, since individual subjects were confined to their own block, blocks were independent from one another. Consequently, interactions between the subject block and other variables were not of interest, and those interaction effects were not included in the model. The sampling schema for the model is included in Table 5.2. The analysis of variance was performed by testing the hypothesis that the means for different factor levels did not vary significantly. This hypothesis was rejected at the 5% level if the data supported the claim that there was a significant difference between the means.

Table 5.2: Sampling Schema.

			Training	No Training
Ergonomic Corset	Assymmetric Motion	Lifting Frequency	Subjects 1...4	Subjects 5..8
Belt	Twist	3/min		
		9/min		
	No Twist	3/min		
		9/min		
No Belt	Twist	3/min		
		9/min		
	No Twist	3/min		
		9/min		

5.2.1 Kinematic Data

There were three categories of kinematic data collected. The angular position at the knees, peak angular velocities, and peak accelerations for the knees and hips were collected for each of the lift conditions.

5.2.1.1 Angular Position

The results of the statistical analysis of variance are contained in Table 5.3 and Table 5.4. Table 5.3 contains the summary of the statistical analysis for the left knee and Table 5.4 contains the summary for the right knee.

Table 5.3: Anova summary table for angular position at the left knee, P_{LK} (in deg).

Source	SS	DF	MS	F-Ratio	P
$S_{j(i)}$	50,551.24	6	8,425.21	27.414	0.000*
T_i	32,160.51	1	32,160.51	104.646	0.000*
A_k	272.476	1	272.476	0.887	0.352
C_l	43.796	1	43.796	0.143	0.708
F_m	740.116	1	740.116	2.408	0.128
TA_{ik}	8.276	1	8.276	0.027	0.870
TC_{il}	8.178	1	8.178	0.027	0.871
TF_{im}	94.860	1	94.860	0.309	0.581
AC_{kl}	642.134	1	642.134	2.089	0.156
AF_{km}	13.530	1	13.530	0.044	0.835
CF_{lm}	3.600	1	3.600	0.012	0.914
TAC_{ikl}	653.491	1	653.491	2.126	0.152
TAF_{ikm}	2.302	1	2.302	0.007	0.931
ACF_{klm}	16.478	1	16.478	0.054	0.818
TCF_{ilm}	364.605	1	364.605	1.186	0.282
$E_{n(ijklm)}$	13,215.07	43	307.327		

Note asterisk effects are significant.

Table 5.4: Anova summary table for angular position at the right knee, P_{RK} (in deg).

Source	SS	DF	MS	F-Ratio	P
$S_{j(i)}$	43,097.42	6	7,182.90	24.264	0.000*
T_i	41,817.16	1	41,817.16	141.259	0.000*
A_k	113.304	1	113.304	0.383	0.539
C_l	82.589	1	82.589	0.279	0.600
F_m	1,331.39	1	1,331.39	4.497	0.040*
TA_{ik}	19.083	1	19.083	0.064	0.801
TC_{il}	126.224	1	126.224	0.426	0.517
TF_{im}	215.975	1	215.975	0.730	0.398
AC_{kl}	439.981	1	439.981	1.486	0.229
AF_{km}	53.708	1	53.708	0.181	0.672
CF_{lm}	50.241	1	50.241	0.170	0.682
TAC_{ikl}	476.587	1	476.587	1.610	0.211
TAF_{ikm}	30.844	1	30.844	0.104	0.748
ACF_{klm}	306.890	1	306.890	1.037	0.314
TCF_{ilm}	68.077	1	68.077	0.230	0.634
$E_{n(ijklm)}$	12,729.40	43	296.033		

Note asterisk effects are significant.

Sources of variation found to be significant were the subject block, training and lifting frequency effects. Post-hoc analyses indicated that subjects without training had a significantly larger angular position than subjects who had been trained. Higher lift frequencies were found to have significantly larger angular positions as well. Larger angular positions indicated that the subject's knees were not as bent as subjects who had smaller angular positions. Therefore, subjects who were not trained lifted with a straighter knee lifting style. The post-hoc analyses were completed with the aid of the Least Significant Range (LSR) mean testing method. Individual calculations and means used for this method are contained in Appendix C.

5.2.1.2 Angular Velocity

The results of the statistical analysis of variance for the angular velocity data are contained in Table 5.5 through Table 5.8. Table 5.5 and Table 5.6 contain the velocity values collected for the knee joint. Table 5.7 and Table 5.8 contain values collected for the hip joint.

Table 5.5: Anova summary table for angular velocity at the left knee, v_{LK} (in deg/sec).

Source	SS	DF	MS	F-Ratio	P
$S_{j(i)}$	84,988.12	6	14,164.686	6.565	0.000*
T_i	2,578.48	1	2,578.48	1.195	0.280
A_k	771.754	1	771.754	0.358	0.553
C_l	4,529.78	1	4,529.78	2.099	0.155
F_m	380.403	1	380.403	0.176	0.677
TA_{ik}	61.115	1	61.115	0.028	0.867
TC_{il}	7,137.63	1	7,137.63	3.308	0.076
TF_{im}	36.066	1	36.066	0.018	0.894
AC_{kl}	7,355.30	1	7,355.30	3.409	0.072
AF_{km}	2,434.98	1	2,434.98	1.128	0.294
CF_{lm}	2,423.66	1	2,423.66	1.123	0.295
TAC_{ikl}	3,139.97	1	3,139.97	1.455	0.234
TAF_{ikm}	622.388	1	622.388	0.288	0.594
ACF_{klm}	18.051	1	18.051	0.008	0.928
TCF_{ilm}	373.490	1	373.490	0.173	0.679
$E_{n(ijklm)}$	92,781.73	43	2,157.72		

Note asterisk effects are significant.

Table 5.6: Anova summary table for angular velocity at the knee, v_{RK} (in deg/sec).

Source	SS	DF	MS	F-Ratio	P
$S_{j(i)}$	78,896.74	6	13,149.46	2.858	0.020*
T_i	10,606.99	1	10,606.99	2.306	0.136
A_k	665.700	1	665.700	0.145	0.706
C_l	14,863.74	1	14,863.74	3.231	0.079
F_m	3,267.74	1	3,267.74	0.710	0.404
TA_{ik}	540.481	1	540.481	0.117	0.733
TC_{il}	1.033	1	1.033	0.000	0.988
TF_{im}	2,050.072	1	2,050.072	0.446	0.508
AC_{kl}	2,525.19	1	2,525.19	0.549	0.463
AF_{km}	18,580.58	1	18,580.58	4.039	0.051
CF_{lm}	10,627.59	1	10,627.59	2.310	0.136
TAC_{ikl}	386.631	1	386.631	0.084	0.773
TAF_{ikm}	2,920.16	1	2,920.16	0.635	0.430
ACF_{klm}	557.666	1	557.666	0.121	0.729
TCF_{ilm}	2,506.95	1	2,506.95	0.545	0.464
$E_{n(ijklm)}$	197,806.83	43	4,600.16		

Note asterisk effects are significant.

Only the subject block was found to be significant. As indicated earlier, the independence of the subject block results in exclusion of its interaction with other effects.

Table 5.7: Anova summary table for angular velocity at the left hip, v_{LH} (in deg/sec).

Source	SS	DF	MS	F-Ratio	P
$S_{j(i)}$	27,986.67	6	4,664.45	1.932	0.097
T_i	33,571.72	1	33,571.72	13.904	0.001*
A_k	1,367.25	1	1,367.25	0.566	0.456
C_l	8,594.40	1	8,594.40	3.560	0.066
F_m	4,707.00	1	4,707.00	1.950	0.170
TA_{ik}	112.685	1	112.685	0.047	0.830
TC_{il}	12,280.84	1	12,280.84	5.086	0.029*
TF_{im}	167.252	1	167.252	0.069	0.794
AC_{kl}	442.057	1	442.057	0.183	0.671
AF_{km}	148.638	1	148.638	0.062	0.805
CF_{lm}	942.905	1	942.905	0.391	0.535
TAC_{ikl}	5.825	1	5.825	0.002	0.961
TAF_{ikm}	736.093	1	736.093	0.305	0.584
ACF_{klm}	312.933	1	312.933	0.130	0.721
TCF_{ilm}	950.250	1	950.250	0.394	0.534
$E_{n(ijklm)}$	103,821.38	43	2,414.45		

Note asterisk effects are significant.

Table 5.8: Anova summary table for angular velocity at the right hip, v_{RH} (in deg/sec).

Source	SS	DF	MS	F-Ratio	P
$S_{j(i)}$	21,907.55	6	3,651.26	1.155	0.348
T_i	21,190.83	1	21,190.83	6.705	0.013*
A_k	6,530.26	1	6,530.26	2.066	0.158
C_l	17,574.00	1	17,574.00	5.561	0.023*
F_m	5,282.16	1	5,282.16	1.671	0.203
TA_{ik}	12,885.37	1	12,885.37	4.077	0.050*
TC_{il}	9,063.50	1	9,063.50	2.868	0.098
TF_{im}	399.464	1	399.464	0.126	0.724
AC_{kl}	30.659	1	30.659	0.010	0.922
AF_{km}	1,444.19	1	1,444.19	0.457	0.503
CF_{lm}	27,398.87	1	27,398.87	8.670	0.005*
TAC_{ikl}	197.536	1	197.536	0.063	0.804
TAF_{ikm}	7.714	1	7.714	0.002	0.961
ACF_{klm}	321.408	1	321.408	0.102	0.751
TCF_{ilm}	831.089	1	831.089	0.263	0.611
$E_{n(ijklm)}$	135,895.55	43	3,160.36		

Note asterisk effects are significant.

Training was found to be a significant factor for both hips. Subjects that were trained had significantly lower velocities at both hip joints. Lower velocities indicated that the subject's lifting style was smoother compared to higher velocities. Using a corset was determined to significantly reduce the velocity at the hip on the right side. There were also three significant interaction effects. For the left hip, the interaction between training and the belt was found to be significant. Analysis showed that an untrained subject without a belt experienced significantly higher hip velocities than either of the trained conditions. For the right hip, the corset by frequency interaction effect was found to be significant. Untrained subjects performing lifting tasks with a 90° twist exhibited

significantly higher velocities than any of the other three conditions. Subjects without a belt and lifting at the higher frequencies experienced higher velocities than any of the other conditions as well.

5.2.1.3 Angular Acceleration

The results of the statistical analysis of variance are contained in Table 5.9 through Table 5.12. Tables 5.9 and 5.10 contain the acceleration values collected for the knee joints and Tables 5.11 and 5.12 contain values collected for the hip joint.

Table 5.9: Anova summary table for angular acceleration at the right knee, a_{LK} (in deg/sec²).

Source	SS	DF	MS	F-Ratio	P
$S_{j(i)}$	1,245,912.18	6	207,652.03	0.751	0.612
T_i	2,279,757.28	1	2,279,757.28	8.247	0.006*
A_k	325,985.67	1	325,985.67	1.179	0.284
C_1	1,961,772.20	1	1,961,772.20	7.097	0.011*
F_m	179,321.08	1	179,321.08	0.649	0.425
TA_{jk}	275,812.51	1	275,812.51	0.998	0.323
TC_{il}	1,317,603.96	1	1,317,603.96	4.766	0.035*
TF_{im}	338,224.66	1	338,224.66	1.224	0.275
AC_{kl}	1,317,383.99	1	1,317,383.99	4.766	0.035*
AF_{km}	904,086.18	1	904,086.18	3.271	0.078
CF_{lm}	66,805.86	1	66,805.86	0.242	0.626
TAC_{ikl}	252,621.34	1	252,621.34	0.914	0.344
TAF_{ikm}	135,756.20	1	135,756.20	0.491	0.487
ACF_{klm}	37,306.51	1	37,306.51	0.135	0.715
TCF_{ilm}	391,620.82	1	391,620.82	1.417	0.240
$E_{n(ijklm)}$	11,886,600	43	276,432.51		

Note asterisk effects are significant.

Table 5.10: Anova summary table for angular acceleration at the right knee, a_{RK} (in deg/sec²).

Source	SS	DF	MS	F-Ratio	P
$S_{j(i)}$	3,208,390.96	6	534,731.83	1.069	0.396
T_i	27,748.77	1	27,748.77	0.055	0.815
A_k	130,251.66	1	130,251.66	0.260	0.612
C_l	1,753,416.44	1	1,753,416.44	3.505	0.068
F_m	1,371,698.60	1	1,371,698.60	2.742	0.105
TA_{ik}	174,207.76	1	174,207.76	0.348	0.558
TC_{il}	968,688.60	1	968,688.60	1.936	0.171
TF_{im}	77,095.33	1	77,095.33	0.154	0.697
AC_{kl}	104,811.48	1	104,811.48	0.210	0.649
AF_{km}	1,625,240.24	1	1,625,240.24	3.249	0.078
CF_{lm}	1,476,081.83	1	1,476,081.83	2.951	0.093
TAC_{ikl}	52,421.71	1	52,421.71	0.105	0.748
TAF_{ikm}	134,160.47	1	134,160.47	0.269	0.607
ACF_{klm}	189,287.74	1	189,287.74	0.378	0.542
TCF_{ilm}	15,871.92	1	15,871.92	0.032	0.859
$E_{n(ijklm)}$	21,510,200	43	500,237.93		

Note asterisk effects are significant.

Training was found to be significant for the left knee. Subjects who were trained were found to have significantly lower knee accelerations. Since acceleration is directly proportional to force, higher accelerations will result in higher reactive forces. Training was found to reduce the reactive forces. Use of a corset was also found to be significant for the left knee. Subjects who used the belts had significantly reduced accelerations for the left knee. There were also two interaction effects, the training by corset interaction effect and the asymmetry by corset interaction effect. Subjects that were neither trained nor wore a belt experienced the highest accelerations at the left knee. Twisting without a belt was found to result in the highest acceleration for the same joint.

Table 5.11: Anova summary table for angular acceleration at the left hip, a_{LH} (in deg/sec²).

Source	SS	DF	MS	F-Ratio	P
$S_{j(i)}$	2,847,383.26	6	474,563.88	2.373	0.046*
T_i	2,723,504.33	1	2,723,504.33	13.616	0.001*
A_k	16,274.26	1	16,274.26	0.081	0.777
C_l	1,229,814.97	1	1,229,814.97	6.148	0.017*
F_m	81,816.44	1	81,816.44	0.409	0.526
TA_{ik}	75,856.71	1	75,856.71	0.379	0.541
TC_{il}	1,343,036.91	1	1,343,036.91	6.714	0.013*
TF_{im}	79,991.05	1	79,991.05	0.400	0.530
AC_{kl}	164,333.76	1	164,333.76	0.822	0.370
AF_{km}	230,504.80	1	230,504.80	1.152	0.289
CF_{im}	678.888	1	678.888	0.003	0.954
TAC_{ikl}	44,148.60	1	44,148.60	0.221	0.641
TAF_{ikm}	13,896.09	1	13,896.09	0.069	0.793
ACF_{klm}	114,875.14	1	114,875.14	0.574	0.453
TCF_{ilm}	48,590.44	1	48,590.44	0.243	0.625
$E_{n(ijklm)}$	8,601,038.81	43	200,024.16		

Note asterisk effects are significant.

Table 5.12: Anova summary table for angular acceleration at the right hip, a_{RH} (in deg/sec²).

Source	SS	DF	MS	F-Ratio	P
$S_{j(i)}$	4,431,218.90	6	738,536.48	1.579	0.176
T_i	3,191,305.83	1	3,191,305.83	6.825	0.012*
A_k	3,182.27	1	3,182.27	0.007	0.935
C_1	1,260,015.27	1	1,260,015.27	2.695	0.108
F_m	810,740.33	1	810,740.33	1.734	0.195
TA_{ik}	1,372,766.51	1	1,372,766.51	2.936	0.094
TC_{il}	6,696.79	1	6,696.79	0.014	0.905
TF_{im}	117,450.90	1	117,450.90	0.251	0.619
AC_{kl}	177,105.27	1	177,105.27	0.379	0.542
AF_{km}	221,427.32	1	221,427.32	0.474	0.495
CF_{lm}	3,314,972.44	1	3,314,972.44	7.090	0.011*
TAC_{ikl}	283,935.07	1	283,935.07	0.607	0.440
TAF_{ikm}	4,397.36	1	4,397.36	0.009	0.923
ACF_{klm}	916.353	1	916.353	0.002	0.965
TCF_{ilm}	105,998.54	1	105,998.54	0.227	0.636
$E_{n(ijklm)}$	20,105,800	43	467,576.55		

Note asterisk effects are significant.

Training was found to be a significant factor for both hips. Subjects who were trained had significantly reduced accelerations for the hip joints over subjects who had not been trained. The use of a corset was also found to be significant for the left hip. Subjects who used the belt experienced significantly lower accelerations. The training by corset interaction was found to be significant for the left hip. Untrained subjects without a belt had substantially higher hip accelerations over any other condition on the right side. The corset by frequency interaction was found to be significant for the right hip. The post-hoc analysis revealed that lifting without a belt at the higher frequency led to higher

accelerations over lifting with a belt at that frequency or without a belt at the lower frequency.

5.2.2 Physiological Measures

Three physiological parameters were collected during the course of the experiment. The results for these data are presented in two groups, blood pressure measurements, and heart rate measurements.

5.2.2.1 Blood Pressure

The results of the statistical analysis of variance for the systolic and diastolic blood pressure data are contained in Table 5.13 and 5.14.

Table 5.13: Anova summary table for Systolic Blood Pressure, SS (in mm of Hg).

Source	SS	DF	MS	F-Ratio	P
$S_{j(i)}$	20,842.22	6	3,473.70	8.581	0.000*
T_i	1,080.77	1	1,080.77	2.670	0.110
A_k	118.266	1	118.266	0.292	0.592
C_l	153.141	1	153.141	0.378	0.542
F_m	236.391	1	236.391	0.584	0.449
TA_{ik}	708.891	1	708.891	1.751	0.193
TC_{il}	31.641	1	31.641	0.078	0.781
TF_{im}	1,016.02	1	1,016.02	2.510	0.120
AC_{kl}	40.641	1	40.641	0.100	0.753
AF_{km}	58.141	1	58.141	0.144	0.707
CF_{lm}	735.766	1	735.766	1.818	0.185
TAC_{ikl}	1,251.39	1	1,251.39	3.091	0.086
TAF_{ikm}	284.766	1	284.766	0.703	0.406
ACF_{klm}	13.141	1	13.141	0.032	0.858
TCF_{ilm}	37.516	1	37.516	0.093	0.762
$E_{n(ijklm)}$	17,406.672	43	404.806		

Note asterisk effects are significant.

Table 5.14: Anova summary table for Diastolic Blood Pressure, DS (in mm of Hg).

Source	SS	DF	MS	F-Ratio	P
$S_{j(i)}$	12,619.86	6	2,103.31	3.711	0.005*
T_i	18.063	1	18.063	0.032	0.859
A_k	81.000	1	81.000	0.143	0.707
C_l	324.000	1	324.000	0.572	0.454
F_m	0.250	1	0.250	0.000	0.983
TA_{ik}	90.250	1	90.250	0.159	0.692
TC_{il}	121.000	1	121.000	0.213	0.646
TF_{im}	2,162.25	1	2,162.25	3.815	0.057
AC_{kl}	588.063	1	588.063	1.038	0.314
AF_{km}	2,002.563	1	2,002.563	3.533	0.067
CF_{lm}	18.062	1	18.062	0.032	0.859
TAC_{ikl}	60.062	1	60.062	0.106	0.746
TAF_{ikm}	105.062	1	105.062	0.185	0.669
ACF_{klm}	2.250	1	2.250	0.004	0.950
TCF_{ilm}	742.563	1	742.563	1.310	0.259
$E_{n(ijklm)}$	24,370.63	43	566.759		

Note asterisk effects are significant.

The only significant source of variation is the natural variance of the subject block for the systolic blood pressure measurements. Otherwise, there was found to be no significance for any of the parameters used to vary the lift.

5.2.2.2 Heart Rate

The results of the statistical analysis of variance for the heart rate data are contained in Table 5.15.

Table 5.15: Anova summary table for Heart Rate, HR (in beats per minute).

Source	SS	DF	MS	F-Ratio	P
$S_{j(i)}$	16,261.59	6	2,710.27	17.250	0.000*
T_i	3,585.02	1	3,585.02	22.818	0.000*
A_k	54.391	1	54.391	0.346	0.559
C_l	1.266	1	1.266	0.008	0.929
F_m	523.266	1	523.266	3.330	0.075
TA_{ik}	9.766	1	9.766	0.062	0.804
TC_{il}	87.891	1	87.891	0.559	0.459
TF_{im}	19.141	1	19.141	0.122	0.729
AC_{kl}	54.391	1	54.391	0.346	0.559
AF_{km}	385.141	1	385.141	2.451	0.125
CF_{lm}	97.516	1	97.516	0.621	0.435
TAC_{ikl}	11.391	1	11.391	0.072	0.789
TAF_{ikm}	594.141	1	594.141	3.782	0.058
ACF_{klm}	6.891	1	6.891	0.044	0.835
TCF_{ilm}	260.016	1	260.016	1.655	0.205
$E_{n(ijklm)}$	6,755.92	43	157.114		

Note asterisk effects are significant.

Besides the subject blocks, only the training effect was found to be significant. Untrained subjects exhibited higher heart rates than subjects who had been trained. Previous data indicated that the lifting styles of subjects was significantly impacted by training. This

impact on lifting style may beneficially impact the physiological measurements of the subject.

5.2.3 Psychophysical Measures

There was only one psychophysical measure taken during the experiment, Rate of Perceived Exertion (RPE). The statistical analysis for the RPE values collected is presented in Table 5.16.

Table 5.16: Anova summary table for Rate of Perceived Exertion, RPE, values.

Source	SS	DF	MS	F-Ratio	P
$S_{j(\theta)}$	213.023	6	35.504	12.808	0.000*
T_i	84.410	1	84.410	30.450	0.000*
A_k	4.254	1	4.254	1.535	0.222
C_l	0.191	1	0.191	0.069	0.794
F_m	177.223	1	177.223	63.931	0.000*
TA_{ik}	2.066	1	2.066	0.745	0.393
TC_{il}	2.441	1	2.441	0.881	0.353
TF_{im}	4.785	1	4.785	1.726	0.196
AC_{kl}	2.848	1	2.848	1.027	0.316
AF_{km}	2.066	1	2.066	0.745	0.393
CF_{lm}	2.441	1	2.441	0.881	0.353
TAC_{ikl}	0.473	1	0.473	0.171	0.682
TAF_{ikm}	9.379	1	9.379	3.383	0.073
ACF_{klm}	1.410	1	1.410	0.509	0.480
TCF_{ilm}	6.566	1	6.566	2.369	0.131
$E_{n(ijklm)}$	119.199	43	2.772		

Note asterisk effects are significant.

Besides variation between subjects blocks, the only factors with a significant impact on RPEs were the lift frequency and training effects. Subjects significantly rated the lifts higher at the 9 lifts per minute lifting frequency. Subjects who had not been trained perceived the task to be easier. This could be attributed to the lifting style used by trained subjects. Trained subjects employed a more squat lifting style which stressed the upper legs. The subjects perceived the legs to be more important than the back with respects to lift comfort. Trained subjects rated the lift as being slightly moderate to moderate while untrained subjects rated the lifts as light to slightly moderate. Therefore, subjects perceived lifts to be more difficult at higher frequencies and with training.

5.3 General Discussion

A summary of the results is included in Table 5.17.

Table 5.17: Summary of significant effects.

Dependent Variable	Significant Factor	Dependent Variable	Significant Factor
P_{LK}	Training	a_{LK}	Assymetry * Belt
P_{RK}	Training	a_{LK}	Training
P_{RK}	Frequency	a_{LK}	Belt
V_{LH}	Training	a_{LH}	Training
V_{LH}	Training * Belt	a_{LH}	Belt
V_{RH}	Training	a_{LH}	Training * Belt
V_{RH}	Belt	a_{RH}	Training
V_{RH}	Belt * Frequency	a_{RH}	Belt * Frequency
V_{RH}	Training * Twist	HR	Training
V_{RK}	Twist * Frequency	RPE	Training
a_{LK}	Training * Belt	RPE	Frequency

Based on the results, subjects exposed to a standardized safe-lifting training session tended to lift with a style generally accepted as minimizing the hazards associated with these activities. With training, subjects tended to have a smaller angular displacement at the knee which would correspond to a more bent-knee lift. As well, peak velocities and accelerations at the hips were smaller when subjects were trained indicating that subjects lifted more slowly and smoothly. Trained subjects experienced lower peak accelerations at the left knee also. Because acceleration is directly proportional to force, lower accelerations would result in lower generated forces in related musculoskeletal systems. Overall the positive impact of lifting belts was not as prevalent as training. There was a relationship between lifting belts and right-side mechanics regarding peak velocities. Belts significantly reduced the velocities for this side of the body. The opposite trend was observed with regards to peak acceleration. Peak accelerations were significantly lower for the right side, while belts were used. There may be a number of explanations for why the effect was one-sided. However, further research needs to be done before any concrete conclusions regarding these effects can be made. Frequency in combination with lifting belts was significant at the right hip for both peak angular velocities and accelerations. Subjects without a lifting belt at higher frequencies experienced higher velocities and accelerations at the right hip. Again this effect was observed to be one-sided.

With regards to the physiological and psychophysical variables measured, only training and lifting frequency had a significant effect. It was observed that untrained subjects had higher heart rates. This could be attributed to trained subjects lifting with a generally smoother, slower lifting style. Trained subjects rated the lifts higher on a perceived exertion scale. This could be attributed to the subjects reporting more stress in the upper-leg during a more squat lifting style.

Overall, the results indicate that safe-lift training may provide a positive effect in the very short term. These data do not support the notion that training will have long-term benefits in reducing lifting hazards. The use of industrial lifting belts, either in combination with or independent of a training program, is unjustified since there appears to be no meaningful or consistent reduction in lifting hazards.

6.0 CONCLUSIONS

6.1 Conclusions

Based on this study of 8 male subjects, the following conclusions were determined:

1. The use of a lifting belt was found to significantly impact lifting style on one side of the body. Velocity values impacted the right side and accelerations impacted the left. The use of a belt reduced the magnitudes of these measurements. The reasons for these one sided effects is unclear.
2. Training proved to positively impact lifting style as well. Subjects that were trained tended to have lower velocity and acceleration values at both the hip and knee joints resulting in lower accelerations at the L5/S1 joint.
3. The ergonomic corsets did not have a substantial impact on the subject's physiological parameters. Training did impact the heart rate, however. Subjects who had been trained exhibited lower heart rates than subjects who had not been trained.
4. Only training and lift frequency had significant impacts on the subject's perceived exertion. Higher lift frequencies were viewed by the subjects to require greater exertion. Trained subjects also reported greater perceived exertion for the lifts. The belts had no significant impact.
5. The use of a complete training program should be employed in a logical manner to control lifting hazards.

6.2 Recommendations for Future Research

Based on the results of the experiment the following topics should prove useful for future research:

1. Female populations should be examined under the same conditions for further validation of the results.
2. Investigation of a more comprehensive set of lifting parameters to enhance the robustness of this research.

3. Expansion of the sample size to enhance the robustness of this research.
4. Further investigation of the impact of training on lifting style that includes de-training techniques and monitoring of their lifting ability over prolonged period of time in order to determine the effective duration of a training effect.
5. The reasons for lifting belts only impacting one side of the body or the other should be investigated further.
6. Kinematic data for the shoulder plane with respect to the hip plane generated during the lifting activity should be analyzed.

REFERENCES

1. Aquilano, N.J., (1968). "A Physiological Evaluation of Time Standards for Strenuous Work as Set by Stopwatch Time Study and Predetermined Motion Time Path Systems". The Journal of Industrial Engineering, 19(9), pp. 425-432.
2. Asfour, S.S., (1980). "Energy Cost Predicting Models", Manual Lifting and Lowering Tasks. Unpublished Ph.D. Dissertation, Texas Technical University, Lubbock, TX.
3. Asfour, S.S., Khalil, T.M., Moty, E.A., Steele, R., and Rosomoff, H.L., (1983). "Back Pain: A Challenge to Productivity". Proceeding of VIIth International Conference on Production Research.
4. Assmussen, E., and Heeboll-Neilson, K., (1962). "Isometric Muscle Strength in Relation to Age in Men and Women, Ergonomics, 5(1), pp. 167-169.
5. Astrand, P.O., and Rodahl, K. (1977), Text Book of Work Physiological, (2nd Ed), New York: McGraw-Hill.
6. Asundi, P., Purswell, J.L., Schlegel, R.E., and Bowen, D., (1993), "Evaluation of Back Belts in the Prevention of Manual Handling Injuries", Proceedings of the M.M. Ayoub Occupational Ergonomics Symposium, pp. 107-110.
7. Ayoub, M.M., Bethea, N.J., Deivanayagan, S., Asfour, S.S., Bakken, G.M., Liles, D., Mital, A., and Sherif, M., (1978), Determination of Modeling of Lifting Capacity, Final Report, HEW(NIOSH) Grant No. 5R010H-00545-02, September.
8. Ayoub, M.M., Mital, A., Asfour, S.S., and Bethea, N.J., (1980), "Review, Evaluation, and Comparison of Models for Predicting Lifting Capacity", Human Factors, 22(3), pp. 257-269.
9. Ayoub, M.M., Selan, J.L., Karwoski, W., and Rao, H.P.R., (1983), "Lifting Capacity Determination", Proceedings of the Bureau of Mines Technology Transfer Symposia, Pittsburgh, PA., August.
10. Ayoub, M.M., (1992), "Problems and Solutions in Material Handling: the State of the Art", Ergonomics, 35, pp.713-728.
11. Bakken, G.M., (1983), Lifting Capacity Determination as a Function of Task Variables, Unpublished Ph.D. Dissertation, Texas Tech University, Lubbock, TX.

12. Bartelink, D.L., (1957), "The Role of Abdominal Pressure in Relieving the Pressure on the Lumbar Intervertebral Discs", J. Bone and Jt. Surg. 39B, pp. 718-725.
13. Brouha, L., (1967), Physiology in Industry, New York: Pergamon Press.
14. Brown, J.R., (1971), Lifting as an Industrial Hazard, Ontario, Canada; Labor Safety Council of Ontario, Ontario Department of Labor.
15. Chaffin, D.B., and Baker, W.H., (1970), "A Biomechanical Model for Analysis of Symmetric Sagittal Plane Lifting", AIIE Transactions, 11(1), pp. 16-27.
16. Chaffin, D.B., and Park, K., (1973), "A Longitudinal Study of Low Back Pain as Associated with Occupational Weight Lifting Factors", American Industrial Hygiene Association Journal, 34, pp. 513-525.
17. Contreras, L.R., Rys, M.J., and Konz, S.A., (1995), "Back Support Belts in Lifting and Lowering Tasks", Advances in Industrial Ergonomics and Safety VII, pp. 727-734.
18. Das, R.K., (1951), Energy Expenditure in Weight Lifting by Different Methods, Ph.D. Dissertation, University of London.
19. Davis, P.R., and Troup, J.D.G., (1964), "Pressures in the Trunk Cavities when Pulling, Pushing and Lifting", Ergonomics, 1, pp. 465-474.
20. Davis, P.R., and Stubbs, D.A., (1978), "A Method of Establishing Safe Handling Forces in Working Situations", Safety In Materials Handling, U.S. Department of Health, Education and Welfare, pp. 34-38.
21. Duggasani, A.R., (1994), An Investigation of the Effect of Ergonomic Corsets on Biomechanical, Physiological and Psychophysical Parameters during Manual Lifting, Unpublished M.S. Thesis, Montana State University, Bozeman, MT.
22. El-Bassoussi, M.M., (1974), A Biomechanical Model for Lifting in the Sagittal Plane, Unpublished Ph.D. Dissertation, Texas Tech University, Lubbock, TX.
23. Franked, V.H., and Nordin, M., (1980), Basic Biomechanics of the Skeletal System, Lea and Febiger, Philadelphia.
24. Frederik, W.S., (1959), "Human Energy Manual Lifting", Modern Material Handling, March pp. 74-76.

25. Fogleman, M., and Smith, J.L., (1995), "The Use of Biomechanical Measures in the Investigation of Changes in Lifting Strategies Over Extended Periods", International Journal of Industrial Ergonomics, 16, pp. 57-71.
26. Garg, A., (1976), A Metabolic Prediction Model for Manual Material Handling Jobs, Ph.D. Dissertation, University of Michigan, Ann Arbor, MI.
27. Garg, A., (1979), "Methods for Estimating Physical Fatigue", Proceedings of AIIE Conference, (San Francisco, CA), pp. 68-75.
28. Garg, A., and Saxena, U., (1979), "Effects of Lifting Frequency and Techniques on Physical Fatigue with Special Reference to Psychophysical Methodology and Metabolic Rate", American Industrial Hygiene Association Journal, 40(10), pp. 894-904.
29. Genaidy, A.M., and Simmons, R.J., (1995), "Can Back Supports Relieve the Load on the Lumbar Spine for Employees Engaged in Industrial Operations?", Ergonomics, 38(5), pp. 996-1010.
30. Grillner, S., Nilson, J., and Thorstensson, A. (1978), "Intra-Abdominal Pressure Changes During Natural Movements in Man", Acta Physiol. Scand. 103, pp.275-283.
31. Hamilton, B.J., and Chase, R.B., (1969), "A Work Physiology Study of the Relative Effects of Pace and Weight in Carton Handling Task", American Institute of Industrial Engineering, 1(2), pp. 106-111.
32. Harman, E.A., Rosentein, R.M., Fryman, P.N., and Nigro, G.A., (1989), "Effects of a Belt on Intra-Abdominal Pressure During Weight Lifting", Medical Science in Sports and Exercise, 21(2), pp. 186-190.
33. Hemborg, B., and Moritz, U., (1985), "Intra-Abdominal Pressure and Trunk Muscle Activity During Lifting", II Chronic Low-Back Patients, Scand. J. Rehab. Med. 17, pp. 5-13.
34. Hemborg, B., and Moritz, U., and Lowing, N., (1985), "Intra-Abdominal Pressure and Trunk Muscle Activity During Lifting", IV The Casual Factors of INtra-Abdominal Pressure Rise, Scand. J. Rehab. Med. 17, pp. 25-38.

35. Herrin, G.D., Chaffin, D.B., and Mach, R.S., (1974), "Criteria for Research on the Hazard of Manual Material Handling", NIOSH Workshop Proceedings, Cincinnati, OH.
36. Jordon, H.H., (1963), Orthopedic Appliances: The Principles and Practice of Brace Construction, Second Ed. (Thomas, C.C., Springfield, IL.).
37. Kamon, E., and Belding, H.S., (1971), "The Physiological Cost of Carrying Loads in Temperature and Hot Environment", Human Factors, 13(2), pp. 153-161.
38. Keith, A., (1923), "Man's Posture: Its Evolution and Disorders", Lecturer IV: The Adaptions of the Abdomen and its Viscera to the Orthograde Posture, Br. Med. J., 1, pp. 587-590.
39. Khalil, T.M., Genaidy, A.M., Asfour, S.S., and Vinciguerra, T., (1985), "Physiological Limits in Lifting", American Industrial Hygiene Association Journal, 46, pp220-224.
40. Klein, B.P., Jensen, R.C., and Sanderson, L.M., (1984), "Assessment of Workers Compensation Claims for Back Strains/Pains", Journal of Occupational Medicine, 26(6), pp. 443-448.
41. Kumar, S., (1971), Studies of the Trunk Mechanics During Physical Activity, Ph.D. Thesis, University of Surrey.
42. Kumar, S., and Davis, P.R., (1973), "The Lumbar Vertebral Innervation and Intra-Abdominal Pressure", Journal of Anatomy 114(1), pp. 47-53.
43. Kumar, S., and Godfrey, C.M., (1986), "Spinal Braces and Abdominal Support", Trends in Ergonomics/Human Factors III (Ed. Karwowski), pp.. 717-726.
44. Marley, R.J., (1987), The Effect of Frequency Upon Physical Work Capacity for Lifting Tasks, Unpublished M.S. Dissertation, Wichita State University, Whichita, KS.
45. Martin, J.B., and Chaffin, D.B., (1972), "Biomechanical Computerized Simulation of Human Strength in Sagittal Plane Activities", AIIE Transactions, 4(1), pp. 19-28.

46. McGill, S.M., Norman, R.W., and Sharratt, M.T., (1990), "The Effect of an Abdominal Belt on Trunk Muscle Activity and Intra-abdominal Pressure During Squat Lifts", Ergonomics 33(2), pp. 147-159.
47. Micheal, E.D., Hutton, K.E., and Horvath, K.E., (1961), "Cardio-Respiratory Responses During Prolonged Exercise", Journal of Applied Physiology, 16, pp. 997.
48. Mital, A., (1980), Effects of Task Variable Interactions in Lifting and Lowering, Unpublished Ph.D. Dissertation, Texas Tech University, Lubbock, TX.
49. Morris, J.M., Lucas, D.B., and Bresler, B., (1961), "Role of the Trunk in Stability of the Spine", Journal of Bone Joint Surgery, 43A, pp. 327.
50. Muller, E.A., (1953), "Physiological Basis of Rest Pauses in Heavy Work", Quarterly Journal of Experimental Physiology, 38, pp. 205-215.
51. Muth, M.B., Ayoub, M.M., and Gruver, W.A., (1978), "A Non-Linear Programming Model for the Design and Evaluation of Lifting Tasks", Safety in Manual Materials Handling, DHEW(NIOSH) Publication No. 78-185, pp. 96-109.
52. NIOSH, (1981), "Work Practices Guide for Manual Lifting", NIOSH Technical Report No. 81-122, National Institute of Occupational Safety and Health, Cincinnati, OH, March.
53. NIOSH, (1994), Workplace Use of Back Belts: Review and Recommendations, NIOSH: Back Belt Working Group, U.S. Department of Health and Human Services, July, 1994.
54. NSC, (1983), "Back Injury Prevention Through Ergonomics", (Videotape), National Safety Council, Chicago, IL.
55. Park, K.S., and Chaffin, D.B., (1974), "A Biomechanical Evaluation of Two Methods of Manual Load Lifting", AIIE Transactions, 6(2), pp. 105-113.
56. Ready, A.E., and Quinney, H.A., (1982), "Alterations in Anaerobic Thresholds as the Result of Endurance Training and Detraining", Medicine and Science in Sports and Exercise, 14(4), pp. 292-296.

57. Rowe, M.L., (1969), "Low Back Pain in Industry: A Position", Journal of Occupational Medicine, 11, pp. 161-169.
58. Rys, M.J., and Konz, S.A., "Lifting Belts?", The Ergonomics of Manual Work, Kansas State University, Manhattan, KS.
59. Smith, J.L., (1980), A Biomechanical Analysis of Experienced and Inexperienced Manual Materials Handlers, Unpublished Ph.D Dissertation, Auburn University, Auburn, AL.
60. Snook, S.H., and Irvine, C.H., (1967), "Maximum Acceptable Weight of Lift", Journal of the American Industrial Hygiene Association, 28, pp. 332-329.
61. Snook, S.H., and Ciriello, J.M., (1974), "The Effects of Heat Stress on Manual Handling Task", American Industrial Hygiene Association, 28, pp. 332-329.
62. Svensson, H.C., and Andersson, G.B.J., 1982, "Low Back Pain in 47 Year Old Men: I. Frequency of Occurrence and Impact on Medical Services", Scandinavian Journal of Rehabilitation Medicine, V14, pp. 47-53.
63. Taber, M., 1982, "Reconstructing the scene, back injury", Occupational Health and Safety, 51, pp 16-22.
64. Troup, J.D.G., 1965, "Relation of Lumbar Spine Disorders to Heavy Manual Work and Lifting", Lancet, pp. 857-861.

APPENDICES

CROSS REFERENCE

Appendix A: Data Collection Forms	20
Appendix B: Experimental Data	24
Appendix C: Statistical Tests	25, 28

APPENDIX A: Data Collection Forms

APPENDIX A-1: Subject Consent Form

SUBJECT CONSENT FORM FOR PARTICIPATION IN ANALYSIS OF LIFTING TASKS IN THREE DIMENSIONS

You have been invited to participate in a study titled "Analysis of Lifting Tasks in Three Dimensions." This study will use motion analysis to determine kinematic data for key joints involved in a lift under a variety of conditions. The results of this experiment are intended to be used to aid Ergonomic practitioners in developing safe lifting requirements for lifting operations. The study may help to answer such questions as to the effectiveness of industrial corsets and may reduce the risk of musculoskeletal injury due to increased knowledge of lifting activities,

The objective of this study is twofold. First, the study is intended to determine kinematic data under controlled lifting conditions. The controlled conditions are the frequency of lifts, 3 and 9 lifts/minute, the twist required by the lifting task, 0 and 90 degrees twist, and the presence on an industrial corset. If you decide to participate, you will be required to lift a weight under each of the three condition categories. Half of the subject group will be trained to lift properly. Each of the 8 trials you will be required to perform, will require 6 minutes of continuous lifting. You will be video taped during the last two minutes of each trial. Following each task, 10 minutes of rest will be allowed before the next trial. Those subjects selected to be trained will have to spend an additional 30 minutes watching a training video prior to performing the first trial. In all, you will be expected to participate for a total of 6 to 6.5 hours over a 2 to 3 day period.

Prior to the experiment, personnel information will be collected. This information will include height, weight, sitting height, arm and leg length, resting blood pressure and heart rate. Because the task involves the musculature of the lower and upper back, as well as the legs some discomfort or stiffness may develop in the affected areas. Neither the

I&ME Department nor Montana State University can provide compensation for such conditions or any other health problems that might arise as a result of this experiment.

You have volunteered for this experiment, but you will never the less be compensated \$30 for your participation. Since your participation is voluntary, you may decide to withdraw from the experiment at any time. Such a withdrawal will forfeit any compensation due you, but it will not affect your relationship, if any, with the I&ME Department or MSU. All information obtained during this experiment of a personal nature will be kept in the strictest confidence.

If you have any questions during the course of the experiment contact either Tom DeBree, (406)-259-4018, or Dr. Robert Marley, (406)-994-3971.

By signing below, you are indicating that you have read all of the above information and are willing to participate. You may keep a copy of this form.

Signature of Participant

Date

Tom DeBree

Date

APPENDIX A-2: Personal Data Collection Form

"Analysis of Lifting Tasks in Three Dimensions" Personal Data Collection Form

SUBJECT NUMBER:

NAME:	
ADDRESS:	
PHONE:	
S.S. #:	

PHYSIOLOGICAL MEASURES:

RESTING HEART RATE:

RESTING BLOOD PRESSURE:

SS:	DS:
-----	-----

ANTHROPOMETRIC MEASURES:

STATURE:

SITTING HEIGHT:

LEG LENGTH:

ARM LENGTH:

GENERAL MEASURES:

BODY WEIGHT:

AGE:

APPENDIX A-3: Experimental Data Collection Form

"Analysis of Lifting Tasks in Three Dimensions" Data Collection Form								
SUBJECT NUMBER: <input style="width: 60px; height: 20px;" type="text"/>				SUBJECT TRAINED? <input style="width: 60px; height: 20px;" type="text"/>				
<i>LIFTING CONDITIONS</i>				TRIAL NUMBER	BLOOD PRESSURE		H.R.	R.P.E.
					SS	DS		
0 DEG TWIST	ERGONOMIC CORSET: YES	3 LIFTS/MIN	7 KG					
			14 KG					
		9 LIFTS/MIN	7 KG					
			14 KG					
	ERGONOMIC CORSET: NO	3 LIFTS/MIN	7 KG					
			14 KG					
		9 LIFTS/MIN	7 KG					
			14 KG					
90 DEG TWIST	ERGONOMIC CORSET: YES	3 LIFTS/MIN	7 KG					
			14 KG					
		9 LIFTS/MIN	7 KG					
			14 KG					
	ERGONOMIC CORSET: NO	3 LIFTS/MIN	7 KG					
			14 KG					
		9 LIFTS/MIN	7 KG					
			14 KG					

APPENDIX B: Experimental Data

APPENDIX B-1: Kinematic Data

LIFTING CONDITIONS					ANG. POSITION		ANGULAR VELOCITY			
Training	Subject	Twist	Belt	Frequency	PLK	PRK	VLK	VLH	VRK	VRH
Trained: No	1	0 deg	Corset: Yes	3/min	54.3473	44.8743	225.0055	183.0234	181.6422	140.1160
				9/min	67.2336	78.6318	128.8802	142.2480	128.1296	14.0702
			Corset: No	3/min	73.6270	76.7167	301.2304	378.4836	351.8540	354.8388
				9/min	96.5535	98.1116	111.1323	156.7668	108.8819	163.5678
		90 deg	Corset: Yes	3/min	70.9707	61.0116	139.3472	163.9410	147.3779	215.8586
				9/min	80.8935	64.6640	123.1733	137.2444	180.1815	162.1345
			Corset: No	3/min	66.1529	72.2215	139.1528	193.9036	112.8438	152.5023
				9/min	59.9914	60.2735	364.3452	398.4447	483.4906	429.8965
	2	0 deg	Corset: Yes	3/min	47.7446	65.3289	145.3124	119.3913	173.3631	131.7713
				9/min	98.2143	97.1244	139.7477	182.9742	143.7375	120.7172
			Corset: No	3/min	105.8721	103.2116	94.4742	148.2058	163.1779	78.8426
				9/min	155.0111	147.6907	65.8100	192.1737	85.0811	206.6869
		90 deg	Corset: Yes	3/min	152.1413	144.8549	58.5389	139.3024	167.2382	195.9205
				9/min	121.9467	117.9562	81.1050	169.0632	151.7645	164.6807
			Corset: No	3/min	96.4533	100.6326	216.3898	237.1524	136.4784	184.0269
				9/min	139.1883	159.3314	110.1433	157.8434	53.6762	187.5892
	3	0 deg	Corset: Yes	3/min	56.4755	60.6060	189.7710	203.6483	236.4526	153.4679
				9/min	51.0412	95.6157	210.4552	195.5700	186.4332	190.1974
			Corset: No	3/min	51.9840	76.2463	168.4390	175.7062	202.6072	147.5146
				9/min	47.2034	70.2880	242.7545	197.1262	156.6605	181.8248
		90 deg	Corset: Yes	3/min	59.6604	69.2396	96.1418	123.8656	163.5661	260.6280
				9/min	48.0897	55.7998	194.1357	178.7269	231.3969	183.8561
			Corset: No	3/min	52.1485	51.3371	205.1561	177.1717	215.7899	250.8413
				9/min	46.8276	41.8509	201.3256	202.8040	280.0732	234.1142
4	0 deg	Corset: Yes	3/min	164.3490	175.7206	59.5901	137.4810	107.5794	171.6586	
			9/min	165.4960	162.2780	60.7315	182.5511	50.9482	166.2304	
		Corset: No	3/min	163.0239	154.0682	34.1997	138.8165	21.0584	145.4684	
			9/min	120.9505	135.1657	161.4328	319.7810	220.9375	304.2075	
	90 deg	Corset: Yes	3/min	149.7528	150.4922	72.5408	123.5445	51.3357	174.3864	
			9/min	162.0213	171.7489	39.7178	169.1388	73.6953	158.5953	
		Corset: No	3/min	119.3016	102.7221	70.9724	152.0463	160.5054	196.6019	
			9/min	171.1215	157.4908	84.3886	139.3879	105.3283	296.8429	

LIFTING CONDITIONS

Training	Subject	Twist	Belt	Frequency	ANG. POSITION		ANGULAR VELOCITY			
					PLK	PRK	VLK	VLH	VRK	VRH
Trained: Yes	1	0 deg	Corset: Yes	3/min	37.0752	38.1375	127.1299	132.5786	234.6251	165.0908
				9/min	41.7033	37.7501	166.8023	148.7649	193.5547	119.4907
			Corset: No	3/min	48.0632	37.2372	147.8291	126.5901	170.2108	118.2873
				9/min	47.8021	42.0466	172.8594	152.8226	138.1202	128.6780
		90 deg	Corset: Yes	3/min	45.3535	37.2241	158.1091	128.7714	169.7726	127.2146
				9/min	36.4993	39.1072	145.2062	132.3213	201.3302	152.6583
	Corset: No	3/min	49.1759	40.7672	130.7895	103.8104	169.6047	134.9072		
		9/min	30.6293	39.0499	197.6265	154.0364	335.5934	174.0298		
	2	0 deg	Corset: Yes	3/min	44.3574	44.3273	168.0935	163.8624	137.1375	116.0005
				9/min	63.0136	57.7802	142.2153	115.1867	140.6081	140.4255
			Corset: No	3/min	50.5861	47.7881	116.1774	93.5877	139.8615	97.1142
				9/min	58.7199	59.2068	137.3734	126.1568	332.2829	283.9428
		90 deg	Corset: Yes	3/min	48.4801	56.0649	141.7251	119.2291	136.2288	136.3285
				9/min	66.1071	61.6262	180.4926	128.8308	190.2577	150.4353
	Corset: No	3/min	65.5479	59.1109	128.4931	105.5091	137.1828	117.6376		
		9/min	67.4355	63.8555	154.2798	119.1084	224.1714	172.2049		
	3	0 deg	Corset: Yes	3/min	67.2177	60.1257	196.7736	130.8729	208.0154	143.1036
				9/min	60.0951	71.2654	120.6845	114.4804	143.5223	138.6938
			Corset: No	3/min	67.2482	66.2574	141.7145	93.5328	156.3469	109.5519
				9/min	67.6366	57.7333	128.3353	127.7655	183.6326	154.9678
		90 deg	Corset: Yes	3/min	53.9816	50.0751	158.7635	129.1283	203.2347	166.7534
				9/min	59.1168	52.6076	143.9993	125.0275	157.7051	121.1247
	Corset: No	3/min	63.5481	60.6483	126.3647	114.1370	158.9944	129.9634		
		9/min	61.8403	67.7607	140.0917	165.2149	216.2246	172.9527		
4	0 deg	Corset: Yes	3/min	42.7418	38.5476	194.0513	147.1946	193.6513	257.1427	
			9/min	41.1915	35.7161	186.5634	223.0753	168.2897	162.6817	
		Corset: No	3/min	29.7337	47.1299	174.7802	180.4578	251.7307	207.7453	
			9/min	46.1147	65.1859	189.4277	201.6534	231.9083	200.0357	
	90 deg	Corset: Yes	3/min	33.1379	29.0616	163.2803	185.2638	159.4211	133.8062	
			9/min	81.5333	43.6209	111.3569	137.4984	145.3831	171.8656	
Corset: No	3/min	59.3810	37.5960	170.3029	159.9845	197.7019	131.5676			
	9/min	46.0529	42.9549	180.0782	165.2672	230.9034	218.6878			

LIFTING CONDITIONS

ANGULAR ACCELERATION

Training	Subject	Twist	Belt	Frequency	ANGULAR ACCELERATION			
					ALK	ALH	ARK	ARP
Trained: No	1	0 deg	Corset: Yes	3/min	743.8319	484.0512	1079.9980	1507.9190
				9/min	431.7363	453.8688	353.5401	141.8078
			Corset: No	3/min	1877.2210	1531.6990	1954.5610	2120.3720
				9/min	386.6178	370.5678	402.6383	439.2635
		90 deg	Corset: Yes	3/min	542.2932	345.1156	405.7752	710.9151
				9/min	571.2175	589.9952	459.9449	649.9410
			Corset: No	3/min	350.3929	579.0788	327.6855	393.6474
				9/min	4196.4380	2196.0000	3964.5080	4427.4730
	2	0 deg	Corset: Yes	3/min	396.5624	300.2534	491.1360	512.3928
				9/min	580.7025	1512.8000	1213.8980	816.1757
			Corset: No	3/min	1103.0000	974.6234	674.5526	383.8619
				9/min	668.7166	962.1950	578.4651	1418.7890
		90 deg	Corset: Yes	3/min	337.8965	470.1281	1310.4440	940.5981
				9/min	435.6605	652.1967	1421.4040	1240.7360
			Corset: No	3/min	1730.3230	1071.3710	962.8810	1018.9600
				9/min	1285.9930	925.4526	512.3183	1086.9520
	3	0 deg	Corset: Yes	3/min	1470.4980	1468.3240	2121.7600	1468.3240
				9/min	1421.8780	743.5111	1658.5260	2521.3780
			Corset: No	3/min	867.6722	1101.9310	1515.5860	1096.9090
				9/min	1388.2260	2238.6450	1119.3730	1944.5230
		90 deg	Corset: Yes	3/min	648.6228	690.3440	2025.0340	2810.1570
				9/min	950.8037	724.5342	1945.1200	1387.3580
			Corset: No	3/min	1782.5520	2686.8650	1217.3110	1994.6560
				9/min	1767.6380	1076.0420	1195.9230	1492.2460
4	0 deg	Corset: Yes	3/min	755.5485	744.1395	977.2604	1413.5360	
			9/min	651.9090	733.7489	227.4671	1172.8010	
		Corset: No	3/min	450.6982	977.1849	301.4834	595.4141	
			9/min	1506.7430	2429.0500	2067.2430	2056.4890	
	90 deg	Corset: Yes	3/min	882.3858	965.5985	591.0982	1255.1960	
			9/min	975.2708	806.2708	1331.7610	882.5236	
		Corset: No	3/min	944.2551	692.1772	550.4238	1131.3320	
			9/min	1684.3390	943.4570	1629.0000	2648.2230	

LIFTING CONDITIONS					ANGULAR ACCELERATION			
Training	Subject	Twist	Belt	Frequency	ALK	ALH	ARK	ARP
Trained: Yes	1	0 deg	Corset: Yes	3/min	497.8343	692.5862	1207.2940	1175.0160
				9/min	1129.5190	1367.8510	1221.0370	634.5972
			Corset: No	3/min	409.5367	423.6482	804.1836	671.1836
				9/min	764.0471	655.8237	778.5467	1517.3280
		90 deg	Corset: Yes	3/min	387.1314	628.9121	621.7216	661.4230
				9/min	616.9657	340.4624	903.3636	1188.2050
			Corset: No	3/min	926.3425	978.1282	1147.7500	866.3612
				9/min	811.9539	644.2357	2221.0810	989.7922
	2	0 deg	Corset: Yes	3/min	359.2511	596.8435	516.4345	426.8871
				9/min	303.3008	313.8012	480.9812	609.3059
			Corset: No	3/min	710.7683	258.8147	1169.6220	1105.3920
				9/min	415.6896	526.2299	3578.0590	2679.7480
		90 deg	Corset: Yes	3/min	409.6468	264.5966	481.5255	463.1191
				9/min	633.7393	354.5682	705.8235	348.1555
			Corset: No	3/min	651.5907	265.2664	899.6888	254.7175
				9/min	734.5410	285.3680	2372.6170	978.7870
	3	0 deg	Corset: Yes	3/min	1744.9580	438.0963	1491.1860	1514.1690
				9/min	399.0921	300.3044	614.5236	490.0453
			Corset: No	3/min	968.8357	266.3867	1223.2790	569.8079
				9/min	530.4080	457.2269	504.4793	831.3847
		90 deg	Corset: Yes	3/min	334.4013	223.0914	666.4588	492.1626
				9/min	437.5389	471.9802	669.4530	520.5117
			Corset: No	3/min	934.3593	683.0848	558.4392	393.2332
				9/min	468.1318	642.7542	1088.1130	588.2786
4	0 deg	Corset: Yes	3/min	737.4199	706.4199	617.5799	1830.8820	
			9/min	602.3851	911.3646	965.6304	741.8456	
		Corset: No	3/min	693.2518	677.8508	1300.4839	1128.6454	
			9/min	496.4320	730.4439	1267.3776	1224.6323	
	90 deg	Corset: Yes	3/min	494.5113	1059.3781	795.3534	680.4757	
			9/min	1261.0536	1048.9855	1052.6033	836.6036	
		Corset: No	3/min	910.6517	1449.8711	1229.0297	1345.8690	
			9/min	933.2623	574.4105	2101.7640	1630.9240	

APPENDIX B-2: Physiological and Psychophysical Data

<i>LIFTING CONDITIONS</i>					BLOOD PRESSURE		HR	RPE
Training	Subject	Twist	Belt	Frequency	SS	DS		
Trained: No	1	0 deg	Corset: Yes	3/min	142	73	79	7
				9/min	105	73	104	13
			Corset: No	3/min	128	77	104	9
				9/min	103	73	99	9
		90 deg	Corset: Yes	3/min	80	78	101	7
				9/min	120	78	95	8
			Corset: No	3/min	120	84	114	9
				9/min	137	79	106	12
	2	0 deg	Corset: Yes	3/min	101	87	83	11
				9/min	102	87	97	12
			Corset: No	3/min	129	109	105	7
				9/min	165	78	88	9
		90 deg	Corset: Yes	3/min	152	62	90	8
				9/min	143	125	103	12
			Corset: No	3/min	142	78	87	13
				9/min	171	72	94	10
	3	0 deg	Corset: Yes	3/min	173	132	102	9
				9/min	132	91	114	14
			Corset: No	3/min	168	147	123	11
				9/min	134	69	125	11
		90 deg	Corset: Yes	3/min	170	95	113	9
				9/min	123	70	102	16.5
			Corset: No	3/min	173	100	105	6
				9/min	141	80	130	13
4	0 deg	Corset: Yes	3/min	173	137	105	6	
			9/min	172	75	96	9	
		Corset: No	3/min	116	61	66	8	
			9/min	135	116	108	10	
	90 deg	Corset: Yes	3/min	155	112	80	7	
			9/min	174	131	109	10	
		Corset: No	3/min	164	108	78	7	
			9/min	163	59	74	10	

<i>LIFTING CONDITIONS</i>					<i>BLOOD PRESSURE</i>		HR	RPE
Training	Subject	Twist	Belt	Frequency	SS	DS		
Trained: Yes	1	0 deg	Corset: Yes	3/min	114	60	64	5
				9/min	68	59	54	11
			Corset: No	3/min	127	102	63	8
				9/min	145	101	64	13
		90 deg	Corset: Yes	3/min	128	101	60	9
				9/min	96	62	60	10
			Corset: No	3/min	73	59	51	12
				9/min	102	80	84	13
	2	0 deg	Corset: Yes	3/min	118	67	73	7
				9/min	148	110	65	11
			Corset: No	3/min	115	69	72	7
				9/min	147	52	78	10
		90 deg	Corset: Yes	3/min	114	63	61	8
				9/min	145	90	68	12
			Corset: No	3/min	113	65	80	8
				9/min	135	79	65	12
	3	0 deg	Corset: Yes	3/min	111	86	106	11
				9/min	141	108	91	16
			Corset: No	3/min	124	112	103	10
				9/min	148	106	89	18
		90 deg	Corset: Yes	3/min	130	88	97	14
				9/min	132	88	88	14
			Corset: No	3/min	123	59	48	12
				9/min	136	113	91	16
4	0 deg	Corset: Yes	3/min	155	136	128	13	
			9/min	173	81	111	18	
		Corset: No	3/min	156	108	102	12	
			9/min	163	107	108	16	
	90 deg	Corset: Yes	3/min	170	123	104	13	
			9/min	165	157	141	17	
		Corset: No	3/min	156	73	101	13	
			9/min	172	166	130	17	

APPENDIX B-3: Means and Standard Deviations

TRAINING: BACK SUPPORT: ASYMMETRIC MOTION: LIFT FREQUENCY:	NO							
	0 deg				90 deg			
	3/min		9/min		3/min		9/min	
	M	S	M	S	M	S	M	S
RESPONSE VARIABLE								
Left Knee Ang. Pos. (P_{LK})	98.63	48.31	104.93	45.34	104.28	60.41	83.51	30.19
Right Knee Ang. Pos. (P_{RK})	102.56	36.58	112.81	35.31	104.74	62.44	81.73	24.58
Left Knee Ang. Vel. (V_{LK})	149.59	115.04	145.28	75.82	190.05	126.56	157.92	67.24
Left Hip Ang. Vel. (V_{LH})	210.30	113.21	216.46	71.19	224.62	118.90	190.07	35.79
Right Knee Ang. Vel. (V_{RK})	184.67	136.02	142.89	59.94	230.64	194.42	156.40	44.11
Right Hip Ang. Vel. (V_{RH})	181.67	119.78	214.07	62.64	287.11	105.19	195.99	41.00
Left Knee Ang. Acc. (A_{LK})	1074.65	599.19	987.58	545.55	2233.60	1325.33	1201.88	685.04
Left Hip Ang. Acc. (A_{LH})	1146.36	263.68	1500.11	995.59	1285.24	610.88	1257.37	975.97
Right Knee Ang. Acc. (A_{RK})	1111.55	757.43	1041.93	478.50	1825.44	1498.31	764.58	400.43
Right Hip Ang. Acc. (A_{RH})	1049.14	774.23	1464.77	738.03	2413.72	1496.62	1134.65	658.81
Heart Rate (HR)	99.50	23.98	105.00	16.64	101.00	23.41	96.00	16.43
Systolic Blood Pressure (SS)	135.25	22.62	134.25	26.32	153.00	16.57	149.75	23.73
Diastolic Blood Pressure (DS)	98.50	38.00	84.00	21.65	72.50	9.68	92.50	13.89
Rate of Perceived Exert. (RPE)	8.75	1.71	9.75	0.96	11.25	1.50	8.75	3.10

TRAINING: BACK SUPPORT: ASYMMETRIC MOTION: LIFT FREQUENCY:	YES							
	0 deg				90 deg			
	3/min		9/min		3/min		9/min	
	M	S	M	S	M	S	M	S
RESPONSE VARIABLE								
Left Knee Ang. Pos. (P_{LK})	80.73	55.87	95.50	50.60	108.13	49.66	103.24	49.48
Right Knee Ang. Pos. (P_{RK})	86.63	60.03	108.41	36.88	106.40	47.83	102.54	53.69
Left Knee Ang. Vel. (V_{LK})	154.92	71.43	134.95	61.29	91.64	35.39	109.53	65.89
Left Hip Ang. Vel. (V_{LH})	160.89	39.11	175.84	23.19	137.66	19.00	163.54	18.11
Right Knee Ang. Vel. (V_{RK})	174.76	52.82	127.31	56.56	132.38	54.71	159.26	65.88
Right Hip Ang. Vel. (V_{RH})	149.25	17.41	122.80	78.01	211.70	36.75	167.32	11.31
Left Knee Ang. Acc. (A_{LK})	841.61	451.12	771.56	443.15	602.80	226.64	733.24	271.24
Left Hip Ang. Acc. (A_{LH})	749.19	512.84	860.98	454.82	617.80	272.27	693.25	93.27
Right Knee Ang. Acc. (A_{RK})	1167.54	686.03	863.36	687.86	1083.09	739.32	1289.56	615.68
Right Hip Ang. Acc. (A_{RH})	1225.54	477.01	1163.04	1001.40	1429.22	947.27	1040.14	335.61
Heart Rate (HR)	92.25	13.15	102.75	8.30	96.00	14.21	102.25	5.74
Systolic Blood Pressure (SS)	147.25	31.12	127.75	32.44	139.25	40.28	140.00	24.86
Diastolic Blood Pressure (DS)	107.25	32.05	81.50	8.85	86.75	21.56	101.00	31.44
Rate of Perceived Exert. (RPE)	8.25	2.22	12.00	2.16	7.75	0.96	11.63	3.64

TRAINING:	YES							
BACK SUPPORT:	NO							
ASYMMETRIC MOTION:	0 deg				90 deg			
LIFT FREQUENCY:	3/min		9/min		3/min		9/min	
	M	S	M	S	M	S	M	S
RESPONSE VARIABLE								
Left Knee Ang. Pos. (P _{LK})	48.91	15.36	55.07	10.07	59.41	7.29	51.49	16.59
Right Knee Ang. Pos. (P _{RK})	49.60	12.11	56.04	9.87	49.53	12.04	53.41	14.50
Left Knee Ang. Vel. (V _{LK})	145.13	24.06	157.00	28.93	138.99	20.96	168.02	25.76
Left Hip Ang. Vel. (V _{LH})	123.54	41.01	152.10	35.22	120.86	26.47	150.91	21.85
Right Knee Ang. Vel. (V _{RK})	179.54	49.70	221.49	83.20	165.87	25.15	251.72	56.23
Right Hip Ang. Vel. (V _{RH})	133.18	50.47	191.91	68.07	128.52	7.54	184.47	22.83
Left Knee Ang. Acc. (A _{LK})	695.60	228.57	551.64	149.55	855.74	136.45	736.97	197.01
Left Hip Ang. Acc. (A _{LH})	406.68	196.10	592.43	123.46	844.09	498.63	536.69	170.69
Right Knee Ang. Acc. (A _{RK})	1124.39	220.13	1532.12	1399.99	958.73	301.39	1945.89	582.50
Right Hip Ang. Acc. (A _{RH})	868.76	289.80	1563.27	795.61	715.05	495.41	1046.95	431.79
Heart Rate (HR)	85.00	20.54	84.75	18.57	70.00	25.21	92.50	27.31
Systolic Blood Pressure (SS)	130.50	17.75	150.75	8.26	116.25	34.19	136.25	28.59
Diastolic Blood Pressure (DS)	97.75	19.60	91.50	26.46	64.00	6.63	109.50	40.85
Rate of Perceived Exert. (RPE)	9.25	2.22	14.25	3.50	11.25	2.22	14.50	2.38

TRAINING:	YES							
BACK SUPPORT:	YES							
ASYMMETRIC MOTION:	0 deg				90 deg			
LIFT FREQUENCY:	3/min		9/min		3/min		9/min	
	M	S	M	S	M	S	M	S
RESPONSE VARIABLE								
Left Knee Ang. Pos. (P _{LK})	47.85	13.29	51.50	11.67	45.24	8.82	60.81	18.72
Right Knee Ang. Pos. (P _{RK})	45.29	10.29	50.63	16.98	43.11	12.23	49.24	9.98
Left Knee Ang. Vel. (V _{LK})	171.51	32.29	154.07	28.71	155.47	9.45	145.26	28.24
Left Hip Ang. Vel. (V _{LH})	143.63	15.35	150.38	51.04	140.60	30.13	130.92	5.30
Right Knee Ang. Vel. (V _{RK})	193.36	41.15	161.49	24.72	167.16	27.84	173.67	26.43
Right Hip Ang. Vel. (V _{RH})	170.33	61.26	140.32	17.67	141.03	17.58	149.02	20.94
Left Knee Ang. Acc. (A _{LK})	834.87	626.52	608.57	369.01	406.42	66.66	737.32	360.27
Left Hip Ang. Acc. (A _{LH})	608.49	123.60	723.33	515.57	544.00	388.96	554.00	335.22
Right Knee Ang. Acc. (A _{RK})	958.12	468.08	820.54	336.25	641.27	129.46	832.81	178.98
Right Hip Ang. Acc. (A _{RH})	1236.74	602.67	618.95	103.37	574.30	112.50	723.37	370.06
Heart Rate (HR)	92.75	29.64	80.25	25.71	80.50	23.27	89.25	36.45
Systolic Blood Pressure (SS)	124.50	20.54	132.50	45.14	135.50	24.08	134.50	29.03
Diastolic Blood Pressure (DS)	87.25	34.31	89.50	24.26	93.75	25.08	99.25	40.56
Rate of Perceived Exert. (RPE)	9.00	3.65	14.00	3.56	11.00	2.94	13.25	2.99

APPENDIX C: Statistical Analysis

APPENDIX C-1: Hypothesis Tests on Means

Means Tests on Descriptive Measures

	Mean	Standard Deviation	Population Mean	<i>t</i> - Value	
Stature	173.51	4.319	175.50	-1.303	At alpha equal to 0.025 for 7 degrees of freedom, <i>t</i> = 2.365
Sitting Height	90.73	2.799	91.50	-0.778	
Leg Length	84.04	3.342	91.50	-6.314 *	
Arm Length	62.93	15.143	79.00	-3.002 *	

* These measures were significantly smaller than the US population.

Test of one mean: $t = \text{Mean} - U_o / (\text{STD} / \text{SQRT}(n))$

Paired *t* test: $t = \text{Mean}(\text{DIF}) - U_o / (\text{STD}(\text{DIF}) / \text{SQRT}(n))$

	Training Group 1	Training Group 1	Difference	
1	86.5	87.3	-0.8	At alpha equal to 0.025 for 3 degrees of freedom, <i>t</i> = 3.182
2	90.0	90.0	0.0	
3	92.0	92.5	-0.5	
4	94.5	93.0	1.5	
	Mean (DIF):		0.05	
	STD (DIF):		1.0214	

t: 0.098

Therefore it can be concluded that the pairs were equally paired.

APPENDIX C-2: Post-hoc Analysis

SINGLE FACTOR SIGNIFICANT EFFECTS

Variable	Condition	Mean	Condition	Mean
P _{LK}	Train: no	97.687	Train: yes	52.554
P _{RK}	Train: no	97.368	Train: yes	52.535
P _{RK}	9/min	79.728	3/min	70.606
V _{LH}	Train: no	184.923	Train: yes	139.116
V _{RH}	Train: no	195.197	Train: yes	154.847
V _{RH}	Belt: no	189.614	Belt: yes	160.429
a _{LK}	Train: no	1055.864	Train: yes	678.392
a _{LK}	Belt: no	1042.207	Belt: yes	692.049
a _{LH}	Train: no	1013.788	Train: yes	601.212
a _{LH}	Belt: no	946.121	Belt: yes	668.879
a _{RH}	Train: no	1365.027	Train: yes	918.422
HR	Train: no	99.343	Train: yes	84.375
RPE	Train: no	9.766	Train: yes	12.063
RPE	9/min	12.578	3/min	9.25

SIGNIFICANT INTERACTION EFFECTS

Variable	Condition	Mean	Condition	Mean	Condition	Mean	Condition	Mean
V _{RK}	90 twist 9/min	203.824	0 twist 3/min	183.082	90 twist 3 /min	163.296	0 twist 9/min	155.455
	LEAST SIGNIFICANT RANGE (LSR)				1	2	3	
					48.07	57.86	63.76	
V _{RH}	Train:no 90 twist	215.53	Train: no 0 twist	174.863	Train:yes 0 twist	158.935	Train:yes 90 twist	150.759
	LEAST SIGNIFICANT RANGE (LSR)				1	2	3	
					39.72	47.8	52.68	
V _{LH}	Train:no Belt:no	210.363	Train:no Belt:yes	159.482	Train:yes Belt:yes	141.380	Train:yes Belt:no	136.852
	LEAST SIGNIFICANT RANGE (LSR)				1	2	3	
					34.77	41.84	46.11	
V _{RH}	Belt:no 9/min	219.389	Belt:yes 3/min	168.078	Belt:no 3/min	159.838	Belt:yes 9/min	152.781
	LEAST SIGNIFICANT RANGE (LSR)				1	2	3	
					39.72	47.8	52.68	
V _{RH}	Train:no 90 twist	215.53	Train:no 0 twist	174.863	Train:yes 0 twist	158.935	Belt:yes 90 twist	150.759
	LEAST SIGNIFICANT RANGE (LSR)				1	2	3	
					39.72	47.8	52.68	
a _{LK}	Train:no Belt:no	1374.427	Train:no Belt:yes	737.301	Train:yes Belt:no	709.988	Train:yes Belt:yes	646.797
	LEAST SIGNIFICANT RANGE (LSR)				1	2	3	
					376.38	452.98	499.2	
a _{LK}	90 twist Belt:no	1257.048	0 twist Belt:no	827.367	0 twist Belt:yes	764.152	90 twist Belt:yes	619.946
	LEAST SIGNIFICANT RANGE (LSR)				1	2	3	
					376.38	452.98	499.2	
a _{LH}	Train:no Belt:no	1297.271	Train:no Belt:yes	730.305	Train:yes Belt:yes	607.453	Train:yes Belt:no	594.972
	LEAST SIGNIFICANT RANGE (LSR)				1	2	3	
					315.91	380.2	418.99	
a _{RH}	Belt:no 9/min	1622.177	Belt:yes 3/min	1116.448	Belt:no 3/min	941.898	Belt:yes 9/min	886.374
	LEAST SIGNIFICANT RANGE (LSR)				1	2	3	
					482.9	581.18	640.48	

MONTANA STATE UNIVERSITY LIBRARIES



3 1762 10224030 4