MONTANA STATE UNIVERSITY

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
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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.

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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)

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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 of 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 refered 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:

Mechanical Work = Load*Frequency*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
Indpendent	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 segement 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 aide 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:

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

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	**Assymetric 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/sec^2).

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_l	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_{ik}	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/sec^2).

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 assymetry 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/sec^2).

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_{lm}	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/sec^2).

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_l	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
$S_{j(i)}$	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