Effects of a 30-minute walk on ground reaction forces during walking with an external load

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EFFECTS OF A 30-MINUTE WALK ON GROUND REACTION FORCES DURING WALKING WITH AN EXTERNAL LOAD

by

Cheryl M. Cardillo
Bachelor of Science
University of Nevada, Reno
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A thesis submitted in partial fulfillment of the requirements for the

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Effects of a 30-Minute Walk on Ground Reaction Forces During Walking with an External Load

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Master of Science in Kinesiology
ABSTRACT

Effects of 30-Minute Walk on Ground Reaction Forces During Walking With an External Load

by

Cheryl M. Cardillo

Dr. John Mercer, Examination Committee Chair
Professor of Kinesiology
University of Nevada, Las Vegas

To investigate effects of a 30-minute walk on kinetics of walking with an external load, ten subjects performed five walking trials across a force platform for five conditions. Walking speed was 1.57m/s for all conditions. The first two conditions had subjects walk without (C1) and with (C2) backpack load. Subjects then walked on a treadmill at 1.57m/s for 30 minutes. At 10 minute intervals GRF data were collected. In comparing C1 and C2, dependent variables F1, F2, and Favg revealed increases of 10.45%, 13.68%, and 11.75% respectively (p<0.01) indicating a mechanical response. No effect for time was observed for any variable tested. Therefore, the null hypothesis that load does not have an effect on vertical GRF was rejected. The null hypothesis that time does not have an effect on vertical GRF was not rejected. Overall, forces were elevated during load carrying, which may result in added stress on anatomical structures.
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CHAPTER 1

INTRODUCTION

Throughout history, people have been looking for ways to make carrying belongings easier. Using various bags, straps, baskets, or other objects for carrying, the search for the most effective way to carry as much as possible has led to the application of loads to various body segments such as the head, back, shoulders, and chest. Load carrying is common practice in the workplace as well as during recreational activities. There are many different kind of packs used daily for carrying. For example, purses, briefcases, backpacks, daypacks, and fanny packs are a few common tools for toting belongings. Some packs are strictly designed to be fashionable while others serve a more productive role. The two-strap backpack is an ordinary tool used to carry objects on our backs. From school to recreational hiking, backpacks are used by adults and children to carry a variety of items.

There is a need for research addressing the question: What effect does carrying an external load have on the human body? In an effort to reduce health care costs, the focus of many studies has been on preventing injuries (Collins & Whittle, 1989; Munro, Miller, & Fuglevand, 1987; Nigg & Bobbert, 1990; Voloshin & Wosk, 1982). Knowledge of the biomechanics of carrying external loads may aid in the prevention of some injuries. Although there has been some research
on the effects of external load on biomechanics during walking, the relationship, if there is one, between external load and overuse injury is not well understood. Nevertheless, there is some evidence that the impact between the foot and the ground during walking and running may be related to overuse injuries (Bobbert, Schamhardt, & Nigg, 1991). It seems reasonable to suspect that an external load would have the effect of increasing the magnitude of impact during locomotion. In order to discuss whether or not there is a relationship between lower extremity overuse injury and load carrying, a discussion of non-weight bearing biomechanics is necessary.

Kinetics is the study of the forces causing motion. In his publication in 1687, Sir Isaac Newton described three laws of motion. The first law of motion is the law of inertia, which describes the resistance of an object to change motion. Logically, the greater the mass of an object, the greater it's resistance to change motion. To move the object, a force must be applied and hence a force must be applied to stop an object already in motion. Newton’s second law of motion is the law of acceleration, represented by the equation $F = ma$. Force is equal to the product of mass and acceleration. Newton’s third law of motion is the law of action-reaction: for every force there is an equal and opposite reaction force. Simply put, if force is exerted on an object, that object will, in turn, exert an equal force in the opposite direction.

Ground reaction forces are a direct application of Newton’s third law of motion. During walking, a force is exerted downward by the body. The ground reaction force (GRF) is the opposing force exerted by the surface pushing back against the body. As a result, energy is absorbed and forces are attenuated.
Ground reaction force patterns are three dimensional in nature and can be broken down into three orthogonal components. The vertical component, Fz, describes force in the vertical direction and generally exhibits the greatest magnitude during walking. The antero-posterior component, Fy, describes force in the forward-backward direction. Finally the medio-lateral component, Fx, describes side-to-side force.

Analyzing GRF patterns during walking is one way to examine the mechanical characteristics that describe walking gait. Additionally, GRF patterns can be used as a basis for comparing normal and abnormal patterns of walking gait (Chao, Laughman, Schneider, & Stauffer, 1983; White, Yack, Tucker, & Lin, 1998). Ground reaction force patterns reflect the acceleration pattern of an object's center of mass (COM). Tracking COM acceleration patterns allows us to quantify gait kinematics, which may be used to identify possible mechanisms for overuse injury.

Factors That Influence GRF Patterns

Various factors may exhibit an effect on GRF patterns. For example, it has been established that walking speed, as well as stride length (SL) and stride frequency (SF), are factors that affect GRF characteristics (Martin & Marsh, 1992; Soames & Richardson, 1985; White et al. 1998). Soames and Richardson reported significant differences in peak reaction forces at heel strike for different speeds of walking as well as for different stride lengths. The authors concluded that cadence should be controlled when comparing GRF patterns during different experimental conditions. In contrast, Martin and Marsh concluded from their
study that constraining SL and SF may affect the kinematics and kinetics of walking and are therefore only in favor of controlling speed. Quite possibly, a response to an experimental condition would be to change SL and SF, which would have an expected effect on GRF patterns. In regards to overuse injury, the observation of changes in GRF patterns is probably more important than SL or SF changes.

Numerous studies have examined the normal kinetic characteristics during walking, but there is a limited amount of research on the effect of applying an external load (i.e. backpack) on kinetics during walking. Previous studies have observed changes in GRF patterns with increases in mass (Bates, Hamill, & DeVita, 1988; Simpson, Bates, & McCaw, 1988; Wiese-Bjornstal & Dufek, 1991). The law of acceleration, Newton's second law, states that force is equal to the product of mass and acceleration. By this law, force will increase when additional mass is carried, as in a backpack. However, an increased GRF is not always observed when mass is increased. For example, Simpson et al. (1988) examined the effects of additional mass on selected GRF parameters and found no significant differences in GRF pattern with added mass.

The absence of a change in GRF patterns with added mass has been described by Caster and Bates (1995) as a neuromuscular response. A neuromuscular response is defined as either a decrease or no change in force. Caster and Bates describe two responses defining a continuum of responses exhibited in response to the addition of an external load. A neuromuscular response as described above is one response. The other response is a mechanical response during which force increases with the addition of mass.
Comparing GRF patterns during landing with and without added mass, Caster and Bates concluded that all subjects, to some degree, exhibited a neuromuscular or protective response to added mass.

Although there has been some research investigating the effect of external load on kinetics, there is minimal research investigating the effect of a long duration application of increased mass on GRF patterns. Logically, the question arises: Does the length of the period of exposure of an external load have an affect on GRF variables? In other words, if a person wears a backpack for an extended period of time, are they exposed to greater forces during the load-carrying period? The objective of this study is to examine ground reaction forces during walking before and after a moderate paced walk while carrying an external load for a period of time. It is hypothesized that the long duration walk will be a factor affecting GRF patterns during walking.

Statement of Problem

The study of the effects of a 30-minute walk on the GRF during walking is important to identifying possible mechanisms for overuse injury. As the general population increases in age, so does the occurrence of degenerative conditions such as osteoarthritis. Impact upon heel strike during walking may be linked to degenerative conditions, osteoarthritis, and low back pain (Bobbert et al. 1991; Munro et al. 1987; Simpson et al. 1988). Recent research has found a correlation between repetitive impact loading and degenerative damage (Collins & Whittle, 1989). Increasing mass by the addition of weight in a backpack and carrying this load for extended time periods may amplify the potential to cause
damage to anatomical structures. The relationship between impact loading and injury provides a basis for investigating the kinetics of walking with an external load. Prevention of injuries due to repetitive loading may be possible with a better understanding of the complex mechanics of walking.

Carrying an increased mass for a period of time may also offer a positive response, however. For example, the addition of mass increases musculoskeletal loading, which may help in maintaining bone density and muscular strength (Salem, Wang, Young, & Greendale, 1999). As stress levels increase, bone mineralization and girth may also increase (Anderson & Hall, 1995).

Statement of Purpose

The purpose of the study was to investigate the effects of a 30-minute walk on the kinetics of walking with an external load in healthy, young adults. Specifically, the study compared selected vertical GRF parameters prior to, during, and after a moderate walk on a treadmill. Kinetic information can be used to understand forces the body is exposed to during load carrying and can be used to address possible mechanisms for injury.

Significance of Study

Backpacks are a common tool used to carry objects on our backs. From school to recreational hiking the backpack is used to carry a variety of items by adults and children. It is known that carrying an external load increases energy expenditure for walking at various speeds (Bhambhani, Buckley, & Maikala,
Studies have also identified an acceptable amount of weight to be carried as well as the placement of such a load to minimize risk of injury (Bobet & Norman, 1984; DeVita, Hong, & Hamill, 1991). However, there is limited research addressing the kinetic effects of carrying an external load during long duration walking. The importance of the study is to understand GRF before and after a 30-minute walk while carrying an external load. This is important because repetitive loading of the human locomotor system has been shown to cause overuse injuries such as the development of osteoarthritis (Nigg, & Bobbert, 1990; Collins & Whittle, 1989; Voloshin & Wosk, 1982). Investigations involving young, healthy adults is important to identify the possible mechanisms leading to overuse injuries and hence the prevention of such injuries.

Hypotheses

The present study was designed to test the following null hypotheses:

1. Application of an external load does not affect the vertical GRF variable, F1 magnitude, of normal walking in healthy, young adults.

2. Application of an external load does not affect the vertical GRF variable, F2 magnitude, of normal walking in healthy, young adults.

3. Application of an external load does not affect the average vertical GRF of normal walking in healthy, young adults.

4. A 30-minute walk with an external load does not affect the vertical GRF variable, F1 magnitude, during normal walking in healthy, young adults.
5. A 30-minute walk with an external load does not affect the vertical GRF variable, F2 magnitude, during normal walking in healthy, young adults.

6. A 30-minute walk with an external load does not affect the average vertical GRF during normal walking in healthy, young adults.

7. A 30-minute walk with an external load does not affect stance time during normal walking in healthy, young adults.

8. A 30-minute walk with an external load does not affect time to F1 during normal walking in healthy, young adults.

Delimitations

The following are delimitations of the present study:

1. Participants had no history of recent injuries that would affect their performance in the study. A brief questionnaire was used to examine each participant's medical history.

2. Participants volunteered from a university student population.

3. Ages of participants ranged from 19-28 years.

4. A motor driven treadmill was used to simulate a long duration walk.

5. A timing light system was used to monitor walking speed across a force platform.

Limitations

Limitations of the present study are as follows:

1. Participants wore their own athletic shoes during testing which does not always represent the type of shoe worn by the general population.
2. Stride length and stride frequency were not constrained.

3. Participants selected the placement of the backpack load according to comfort level, therefore load placement varied.

4. For the purpose of data collection, participants had to step off and back on the treadmill during testing.

5. Conditions of the long duration walk could not be randomized to prevent anticipation.

Assumptions

The following assumptions were made for the present study:

1. A long duration walk on a motor driven treadmill adequately represented routine walking of a student.

2. Walking speed was controlled so any changes in GRF patterns are a result of the experimental manipulation of time.

3. The backpack load used during testing was similar to a college student’s typical backpack load.

4. Placement of the backpack load was not a factor affecting the GRF patterns.

Definitions of Terms

The following definitions describe the specific use of terms in the present study:

**Force:** The reaction of the resistance of an object to displacement or motion, or both (ASTM Standards).
**Ground Reaction Force (GRF):** The reaction force provided by the surface upon which one is moving (Hamill & Knutzen, 1995).

**Impact Peak:** high-frequency force peak in the vertical ground reaction force (Fz) occurring in the first 50 ms of ground contact (Bobbert et al., 1991).

**Mechanical Response:** no change in the neuromuscular activity pattern, with expected force increases or decreases attributed solely to the addition of mass (Caster & Bates, 1995).

**Neuromuscular Response:** a response to the addition of mass resulting in a decrease or no change in impact force; may be the result of a perceived danger to the system with the increase in mass (Caster & Bates, 1995).

**Osteoarthritis:** a degenerative wear-and-tear process; musculo-skeletal degeneration (Collins & Whittle, 1989)

**Stride Frequency:** The number of strides per minute (Hamill & Knutzen, 1995).

**Stride Length:** The distance traveled during one stride (Hamill & Knutzen, 1995).
CHAPTER 2

REVIEW OF LITERATURE

The purpose of the study was to investigate the effects of a long duration walk on the kinetics of walking with an external load in healthy, young adults. Specifically, the study compared selected vertical GRF parameters prior to, during, and after a moderate walk on a treadmill. Literature important to understanding GRF patterns as related to human walking gait is presented in this chapter. General information on the GRF patterns during walking gait is presented, followed by literature related to load accommodation during walking. Next, research involving impact peak as related to overuse type injuries and shock attenuation is provided. Finally, physiological responses of the human body while carrying external loads during exercise are addressed.

Mechanics of Normal Walking

Walking is an every day task that is performed with ease and with little thought for most individuals. However, the walking gait pattern is a complex motor control process that involves generating sufficient joint torques and coordinating forces generated by various muscles crossing the joints of the lower limbs to prevent collapse during support as well as provide propulsive force for locomotion. Kinematically, the walking pattern can be broken down into two
phases: support and swing. Important discrete events within the support phase included heel-strike (start of stance phase), foot-flat, midstance, heel-off, and toe-off (end of stance phase). Unlike running, a period of double support is observed during walking when both feet are in contact with the ground. The swing phase of gait begins with toe-off and ends with heel strike (Luttgens, Deutsch, & Hamilton, 1992).

The term "stride" is often used to describe walking gait and for the purpose of this study, is defined as heel strike of one foot to the next heel strike of the same foot. Stride length (SL) is the distance covered during one stride. Stride frequency (SF) is the number of strides per minute (Luttgens et al. 1992). It is known that walking speed affects GRF characteristics as well as the kinematics of walking. However, the effects of changing SL and SF on GRF variables are not consistent between studies.

Several research studies have shown that SL is a factor affecting forces. For example, Soames and Richardson (1985) examined the influence of changes in SL or SF on GRF variables. Velocity of walking is the product of stride length and cadence, and therefore increasing either SL or SF results in an increase in velocity if the other parameter is held constant. For the purpose of their study, 12 subjects performed walking trials across a force platform during which SL and SF were constrained. Stride length was standardized at 50%, 75%, and 100% of leg length and SF was constrained to 42, 52, or 62 steps per minute. Force peaks at heel strike and toe off were normalized to body weight. Peak forces at heel strike and toe off were found to increase with increasing velocity. Significant differences (p < 0.01) were found in the peak GRF at heel strike for both SL and
SF changes. However, the finding of no significant interaction between SL and SF indicates they are independent factors. Effects of changing SF were found to be more prominent than the effects of changing SL. According to the results constraint of velocity alone is not suggested when comparing GRF patterns. Soames and Richardson concluded that SL and SF had a significant influence on selected GRF variables with the effects of SF appearing more prominent than the effects of SL, and therefore recommend constraining SF when possible.

In contrast, constraint of SL and SF is not supported by Martin and Marsh (1992). Preferred SL and SF were determined for ten subjects walking on a treadmill at their own preferred walking speed (approximately 1.43 m/s). Next subjects performed five trials for five different SL and SF combinations. Peak GRF characteristics in the vertical direction showed little change as SL increased. Vertical impulse was found to be significant as SL increased. Results indicated that SF and speed are dependent and constraint would prevent evaluation of normal gait kinematics and kinetics. Therefore Martin and Marsh support controlling speed but not SL and SF.

During walking, external work must be done in order to maintain performance (Cavagna & Margaria, 1966). Total support phase work during walking is greater compared to running due to longer support times observed in walking (Dufek, Schot, & Bates, 1990). In 1989, Winter analyzed motor patterns of walking gait and determined three tasks necessary for safe walking. First support of the upper body against gravity must be maintained to prevent collapse of the lower limbs. Second, posture and balance are needed to keep from falling over in the anterior-posterior or lateral directions. Third, control of foot trajectory...
is needed for gentle heel/toe landing. Previous work by Winter (1980) indicates that during the stance period, the sum of all extensor moments at the ankle, knee, and hip must be positive. Results suggest that one joint has the ability to compensate for a lack in support of another joint, and collapse of the lower limb can be prevented by collaboration of muscles at all three joints. It is evident that the joints of the lower limb are dependent upon each other during support and that examination of a single joint can lead to errors.

Walking Ground Reaction Force Characteristics

Investigation of human gait involves an understanding of the principles that allow us to move. Locomotion is possible because of forces that cause changes in motion. A force is defined as the reaction of the resistance of an object to displacement or motion, or both; therefore the interaction between two objects tending to cause motion is a force. Sir Isaac Newton has been given credit for explaining motion with his three laws of motion. Newton's first law of motion is the law of inertia, which states that an object will remain at rest or continue in motion in a straight line until acted upon by a force. Newton's second law of motion is the law of acceleration, stating that force is equal to the product of mass and acceleration. Last, Newton's third law of motion is the law of action-reaction. This law states that for every force there is an equal and opposite reaction force.

The GRF is a direct application of Newton's third law of motion. During walking, the heel contacts the ground with a force followed by the forefoot contacting the ground with a force, in return the ground exerts an equal force
back in the same direction. The GRF changes in both magnitude and direction during contact with the ground. The orthogonal components of a GRF are: Fz, Fy, and Fx. Fz is the vertical component and generally exhibits the greatest magnitude during walking. Fy is the antero-posterior component and represents forwards and backwards forces. Fx is the medio-lateral component and represents side-to-side forces. Fy and Fx are considered shear components acting parallel to the ground. Characteristics of a vertical GRF curve are typically described using parameters such as: F1, Fmin, and F2. F1 is identified as the first peak on the curve and generally is the greatest in magnitude. F2 is the second peak. Fmin is the lowest point between F1 and F2. Favg is the average force during contact with force platform. See Figure I for an example of a GRF curve.

The basic task of walking involves motion in all three directions (Hamill & Knutzen, 1995). Ground reaction force characteristics reflect the acceleration patterns of the center of gravity of a person and describe the mechanics of both running and walking gait (Munro et al. 1987). A typical vertical GRF pattern for normal walking gait has two characteristic peaks (Winter, 1980). The two maximum peaks are referred to as F1 and F2. Total support time is represented by the pattern between heel contact and toe off. Average Fz reflects the average vertical force exerted during the support phase (Munro et al.). Time histories of occurrence of the mentioned discrete force variables are also good descriptors of gait.

There are several factors that have an effect on GRF patterns. For example, during running and walking, speed has an effect on GRF patterns...
Figure 1. Sample walking GRF curve starting with heel contact and ending at toe off.
Dufek et al. (1990) evaluated lower extremity characteristics of males and females during walking and running. They found that kinetics were related to speed; as speed increased, force increased. F1, average Fz, and time to F1 exhibited significant increases. No significant differences were found between sexes.

In comparing over ground walking to treadmill walking, White et al. (1998) found no significant difference between the two modes of walking for speed, SF, or SL. Results from the study indicate that peak vertical GRF for both modes of walking increases as speed increases and led the authors to conclude that GRF patterns dependent on speed. In a similar study by Munro et al. (1987) GRF patterns were found to be running speed dependent. Subjects performed running trials across a force platform at various speeds resulting in significant increases in GRF variables as speed increased. Locomotion speed has also been shown to have an effect on the lower extremity kinematics. For example as previously mentioned, SL and SF have been found to have an effect on GRF pattern criteria. Generally, as SL and/or SF increase, increases are observed in the peak forces, although results are not always consistent.

Another factor affecting GRF patterns is subject mass. According to Newton’s laws of motion, mass can have an effect on forces. The law of acceleration relates force, mass, and acceleration in the following equation: \( F = ma \). According to the equation, if there is an increase in mass (i.e.: backpack load), there must be a change in force in order for acceleration to remain
constant. When additional mass is added, the subject has a choice of responses to the load. The subject can choose to ignore the load or acknowledge the load and make some type of change to accommodate for the added mass. If the subject ignores the load, an increase in force equal to the load is observed. If the subject acknowledges the load there may be no change in force or a decrease in force (Caster & Bates, 1994). This is made possible by a change in kinematics and can vary among individuals. The idea that each individual exhibits different strategies of accommodation to a load is supported by Bates et al. (1988). Caster and Bates further define the two possible responses to the addition of mass as 1) a neuromuscular strategy, and 2) a mechanical strategy. A neuromuscular strategy implies that the subject perceives the addition of mass to be a danger and therefore a decrease or no change in force is observed. A mechanical strategy implies that the subject does not perceive the addition of mass as a danger and an increase in GRF equal to the mass of the load is observed. The type of strategy an individual exhibits to a load is an example of accommodation.

The effects of additional mass on vertical GRF parameters were investigated by Simpson et al. (1988). Five subjects performed four sets of 25 trials across a force platform for each of two load conditions (HL = 1020g and LL = 454g). Peak F1 forces were not significantly different between load conditions. F2 and average Fz showed significant differences (mean absolute difference 1.2% with increase during the HL condition). The effect of adding the weight revealed 10.5, 3.8, and 5.5% increases for F1, F2, and average Fz forces for three of the five subjects when comparing HL to LL. The other two subjects
showed decreased values during HL vs. LL. An average decrease of 7% and 7.1% for the HL and LL conditions was observed when the weight was removed. Results of the no load conditions were inconsistent. The results also indicated that each individual responded differently to the addition and removal of the load. Simpson et al. suggest that the strategy an individual exhibits is possibly due to a perceived danger. Two subjects exhibited a protective response to the loads, resulting in a decrease in F1 and F2 values while an increase in F1 was observed for the other three subjects. Thus the change in GRF patterns observed with the addition of a load depended on the individual response strategy. Similar results were found in a study by Wiese-Bjornstal and Dufek (1991). Wiese-Bjornstal and Dufek observed significantly greater peak GRF values during a no load condition compared to loaded conditions.

For the purpose of the present study all data were normalized to body weight (BW), no load. By normalizing to the no load condition, we are able to test the null hypothesis that the application of an external load does not affect the vertical GRF pattern of normal walking in healthy young adults. Another technique is to normalize all the data to the system weight (body weight + backpack weight). This method would allow for the analysis of change in GRF relative to system weight.

Walking With a Load

The application of an external load during walking can have various effects on the kinetics and kinematics of walking. The placement and mass of a load are related to exertion and sometimes injury. Johnson, Pelot, Doan, and
Stevenson (1999) suggest that load placement close to the body's center of gravity is optimal in reducing the energy required to carry a load. Selected kinematic variables exhibited significant differences for the different load locations. Distribution of the load among the front and back of the subject resulted in a more normal kinematic walking pattern indicating a lower energy cost. Asymmetric load carrying has been related to high incidences of injury. Devita et al. (1991) investigated the biomechanical effects of asymmetric load carrying during walking and found significant changes in kinematics during walking with an asymmetric load.

During walking and running, the force generated at heel strike has been related to the occurrence of overuse injuries of the lower extremities. These high-frequency forces are known as heel transients or impact peaks and can be seen on the vertical GRF pattern during running and occasionally during walking (Bobbert et al. 1991). The force at heel strike sends shock waves through the lower extremities, which may lead to degenerative conditions of the joints such as osteoarthritis (Bobbert et al. 1991; Collins & Whittle, 1989; Dickinson, Cook, & Leinhardt, 1985; Voloshin & Wosk. 1982). Shock attenuation is the dissipation and absorption of energy from the force generated at heel strike (Voloshin & Wosk, 1982). In contrast Salem et al. (1999) suggest that wearing a weighted vest during walking could possibly reduce age related bone loss. Buckley and Young (1999) speculated that continued exercise in a fatigued state might also lead to an increase in injury. In their study Buckley and Young investigated loaded walking over time to determine if there were changes in GRF patterns as a result of time. Results indicated a significant effect for time in the selected
GRF variables. Continued exercise leading to fatigue resulted in a decreased magnitude of F2 (1.24 to 1.19 body weight (BW)) and SL (1.73 m to 1.68 m) in conjunction with an increase in cadence. Over time, changes in GRF characteristics were observed in 12 subjects walking on a treadmill at 1.78 m/s for 90 minutes with a 25 kg external load. They concluded that a decreased F2 indicates a change in lower limb kinematics due to fatigue that may impose a risk of injury because of the body's decreased capacity to handle the load.

Physiological responses to carrying a load have been studied in depth. Walking with an external load has been found to increase VO$_2$ max and heart rate (Bhambhani et al. 1997; Holewijn, 1990). Bhambhani et al. observed significant increases in VO2 by 50% and 70% during walking with a 15kg and 20kg load compared to unloaded walking. In addition to an increase in VO2, they observed a 36% increase heart rate when compared to the unloaded condition. Energy cost increases with an increase in mass and time (Bhambhani et al. 1997; Epstein et al. 1988; Holewijn, 1990; Patton et al. 1991). Epstein et al. examined the effect of load carrying on the energy cost of prolonged walking. Subjects walked for 120 minutes at 1.25m/s with a 25 or 40 kg load. At work intensities greater than 50% VO$_2$ max, energy costs increased. Epstein et al. showed that energy cost increased in a linear fashion over time and was significant between 25 and 40 minutes and after 100 minutes of walking, indicating that subjects were becoming fatigued.

Patton et al. (1991) studied the energy cost of prolonged walking at three different speeds (1.1m/s, 1.35m/s, and 1.6m/s) with three different external loads (no load, 31.5kg and 49.4kg). They observed a 10-18% increase in VO2 when
comparing unloaded and loaded condition and no change in VO2 over time in the unloaded condition at all speeds. In a similar study by Holewijn (1990), both heart rate and oxygen uptake were significantly affected by mass carried. Holewijn observed a significant increase in average heart rate of 9 beats/min during standing when the load was applied. A significant increase of 1.5% VO2 was observed for the 5.4kg load, and 4.8% VO2 with the 10.4kg load.
CHAPTER 3

METHODS

The purpose of this study was to investigate the effects of a 30-minute walk on the kinetics of walking with an external load in healthy, young adults. Specifically, the study compared selected vertical GRF parameters prior to, during, and after a moderate walk on a treadmill.

This chapter provides a description of the methodology of the study. The chapter addresses participant selection, followed by a description of the experimental protocol and specific conditions of the study along with an explanation of the instrumentation and procedures used to collect and analyze the data.

Participants

Ten young, adult volunteers (ages 19-28 years) were recruited from the student population at the University of Nevada, Las Vegas. This population was selected to represent healthy, young adults. Table 1 presents individual subject characteristics. Approval for the study was provided by the University of Nevada, Las Vegas Office of Sponsored Programs for research involving human subjects (Appendix I).
<table>
<thead>
<tr>
<th>Subject Number</th>
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<th>Gender</th>
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<td>23</td>
<td>F</td>
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<tr>
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<td>M</td>
</tr>
<tr>
<td>3</td>
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<td>19</td>
<td>F</td>
</tr>
<tr>
<td>4</td>
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<td>27</td>
<td>M</td>
</tr>
<tr>
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<td>M</td>
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</tr>
<tr>
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<td>M</td>
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<td>9</td>
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<tr>
<td>10</td>
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<tr>
<th></th>
<th>Means</th>
<th>Std. Dev</th>
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<td>161.8</td>
</tr>
<tr>
<td></td>
<td>23.2</td>
<td>2.7</td>
</tr>
</tbody>
</table>
After reading a description of the experimental procedures, subjects signed a university approved informed consent form (Appendix I). Subjects also completed a brief health related questionnaire along with a "Physical Activity Readiness Questionnaire" (Appendix I) to indicate they were healthy prior to involvement in the study. Subjects were informed that they could terminate their participation in the study at any time.

Instrumentation

A common two shoulder strap backpack (Jansport model #43968) with an absolute mass of 12.45kg was used for the loaded conditions for all subjects. Standard free-weights were used to achieve the mass of the backpack load.

A motor driven treadmill was used to simulate a long duration walk. Walking speed was controlled at 1.57 m/s (3.5mph) for all testing conditions. Published data indicates that a speed of 1.4 m/s is a comfortable walking speed for healthy adults (Hreljac, 1993; Martin & Marsh, 1992). A constant speed of 1.57 m/s was considered a moderate walking speed that was slightly faster than the reported comfortable walking speed for adults.

GRF data were recorded as each subject walked across a force platform (Kistler 9281 B), mounted flush with the floor surface in the middle of a 15m walkway. The force platform consists of four piezoelectric sensors, one located in each corner of the platform. When force is applied to the platform, piezoelectric signals are generated. These signals are then amplified and transmitted to an A/D board. Kistler Bioware (version 3.0) software was used to analyze the resulting digital signals. For each trial, data were recorded for two
seconds at a frequency of 1000Hz. Data collection started just before heel strike and continued beyond toe off in order that the forces during the entire stance phase could be recorded.

Infrared timing lights (Lafayette, Inc. 54035A) were used to monitor walking speed while walking across the force platform. Timing lights were set up an equal distance before and after the force platform. A walking speed within ± 5% of 1.57 m/s and good foot contact with the force platform during data collection was considered an acceptable trial.

The 6-20 point scale for rating of perceived exertion (RPE) (Mahler, Froelicher, Miller, & York, 1995) was used during the long duration walk to give an indication of exertion. A heart rate monitor (Polar, Accurex, NY) was used during the 30-minute walk. Heart rate and RPE ratings were used for a descriptive comparison of physiological intensity of the 30-minute walk for each subject.

Experimental Protocol

Prior to testing, each participant was allowed time to perform a self directed stretch and warm up routine. Participants practiced walking on the treadmill until comfortable, and subsequently across the force platform to become accustomed to landing on the force platform in a consistent, natural manner. Right or left foot contact on the force platform was not controlled because of the symmetry of normal human walking gait (Chao, Laughman, Schneider, & Stauffer, 1983). Although targeting the force platform was discouraged, subtle visual targeting was not considered a factor affecting GRF pattern (Grabiner, Feuerbach, Lundin, & Davis, 1995). After becoming
comfortable walking across the force platform, a participant practiced walking at
the set speed (1.57 m/s). Verbal instructions during the testing period were given
to each participant in a consistent manner. Heart rate and RPE scores were
recorded every three minutes during the treadmill-walking portion of testing.
GRF data collection for each set of trials was limited to three minutes to acquire
the five acceptable trials. Subjects were highly encouraged to return to the
treadmill immediately following completion of the fifth successful trial to minimize
any recovery. Testing took approximately one hour for each subject. After
testing was complete, questions were answered for the participant.

Description of Conditions

The testing session consisted of five conditions. With the exception of
Condition 1, each testing condition involved wearing a backpack with an 12.45kg
load while walking. Conditions 3, 4, and 5, involved a long duration walk on a
treadmill at a set speed.

Condition 1 (C1), no load: Ground reaction force data were collected
without the backpack load by having each subject walk across the force platform
at the set speed. Five acceptable trials were recorded. After completion of C1,
the subject was fitted with the backpack load (adjusted for comfort).

Condition 2 (C2), load, t = 0: each subject walked with the backpack load
across the force platform at the set, controlled speed (1.57 m/s) for data
collection. Upon completing C2, the subject stepped up onto the treadmill, and
the belt was started and set at a constant speed of 1.57 m/s. The subject walked
with the backpack load at the set speed for ten minutes.
Condition 3 (C3), load, t = 10 minutes: after ten minutes, the subject stepped down off the treadmill and walked, at the predetermined speed, across the force platform for data collection. The treadmill belt was left running while the subject completed the trials across the force platform. Upon completion of C3, the subject returned to walking on the treadmill at the set speed for another ten minutes.

Condition 4 (C4), load, t = 20 minutes: after an additional ten minutes of walking, the subject stepped off the treadmill again and performed walking trials across the force platform at the set speed. As soon as data collection was complete for C4, the subject returned to walking on the treadmill at the set speed for another ten minutes.

Condition 5 (C5), load, t = 30 minutes: after an additional ten minutes of walking, the subject stepped off the treadmill and performed walking trials across the force platform at the set speed. Once data were collected, the testing session was officially completed.

Analyses

The present study was a repeated measures design with walk time as the independent, repeated variable. The five levels of the independent variable time were no load, load at t0, t10, t20, and t30. The dependent variables measured for analysis were selected GRF variables: F1, time to F1, average Fz, and total support time. GRF data for each trial for all conditions were normalized to body weight. Averages for each dependent variable were calculated for all subjects. One way repeated measures analysis of variance (ANOVA) was the statistical
test used to analyze the data. Because five dependent variables were analyzed, the Bonferroni adjustment ($\alpha/\# \text{ of dependent variables}$) was used. For the present study, the adjusted $\alpha$-level was set at 0.01. Planned comparisons were completed to determine if there were differences in dependent variables between C1 and C2, C2 and C3, C2 and C4, C2 and C5.
CHAPTER 4

RESULTS

The purpose of the study was to investigate the effects of a 30-minute walk on the kinetics of walking with an external load in healthy, young adults. Specifically, the study compared selected vertical GRF parameters prior to, during, and after a moderate walk on a treadmill. Ground reaction force variables were examined for variations in magnitude relative to body weight.

Data were collected for ten volunteers who were familiar with carrying a typical school backpack. Individual as well as group interpolated GRF data are presented in Appendix II. Three variables describing selected components of the walking GRF curve and two temporal variables were examined during walking without load, walking with load and walking with load at the 10, 20, & 30-minute mark of a treadmill walk.

No Load Compared to Loaded Walking

The first null hypothesis, that an external load does not affect the vertical GRF variable, F1 magnitude, was rejected. The omnibus F ratio indicated a significant difference for F1 [F (4,36) = 19.9, p < 0.01]. Planned comparisons yielded a 10.4% significant increase for F1 magnitude (Figure 2) during the
Figure 2. Mean first maximum vertical force (F1) relative to body weight (BW) (+SE) for each experimental condition.

Notes: Units are in multiples of body weight

Planned Comparisons indicated:
- *No Load vs. Load pre-walk different (p<0.01)
- Load pre-walk vs. Load 10-min. no different (p>0.01)
- Load pre-walk vs. Load 20-min. no different (p>0.01)
- Load pre-walk vs. Load 30-min. no different (p>0.01)
loaded pre-walk condition compared to the non-loaded pre-walk condition \( F(1, 9) = 25.1, p < 0.01 \).

The second null hypothesis, that an external load does not affect the vertical GRF variable, F2 magnitude, was rejected. A significant increase was observed for F2 \( F(4, 36) = 104.7, p < 0.01 \). Planned comparisons yielded a 13.7% significant increase in F2 (Figure 3) magnitude during the loaded pre-walk condition compared to the non-loaded pre-walk condition was observed \( F(1, 9) = 130.2, p < 0.01 \).

The third null hypothesis, that the external load does not affect the average vertical force was rejected. \( F_{avg} \) revealed a significant increase \( F(4, 36) = 161.1, p < 0.01 \). Planned comparisons yielded an 11.8% significant increase in average vertical force magnitude (Figure 4) during the loaded pre-walk condition compared to the non-loaded pre-walk condition \( F(1, 9) = 215.9, p < 0.01 \).

Overall, compared to the non-loaded condition, vertical ground reaction force increased significantly when the load was applied. There was no change in mean stance time (\( \bar{X} = 0.62s, SD = 0.03 \)) or time to F1 (\( \bar{X} = 135.14ms, SD = 17.3 \)) during the loaded pre-walk condition compared to the non-loaded pre-walk condition (\( p > 0.05 \)).

Loaded Pre-walk Compared to Loaded 10, 20, & 30 Minutes

Based on the planned comparisons the study failed to reject the fourth null hypothesis: a 30-minute walk with an external load does not affect the vertical GRF variable, F1 magnitude, during walking. Examination of F1 during loaded
Figure 3. Mean second maximum vertical force (F2) relative to body weight (BW) (+SE) for each experimental condition.

Notes: Units are in multiples of body weight

Planned Comparisons indicated:
*No Load vs. Load pre-walk different (p<0.01)
Load pre-walk vs. Load 10-min. no different (p>0.01)
Load pre-walk vs. Load 20-min. no different (p>0.01)
Load pre-walk vs. Load 30-min. no different (p>0.01)
Average Vertical Force During No-load & Loaded Walking Conditions

Figure 4. Mean average vertical force (Favg) relative to body weight (BW) (+SE) for each experimental condition.

Notes: Units are in multiples of body weight

Planned Comparisons Indicated:
*No Load vs. Load pre-walk different (p<0.01)
Load pre-walk vs. Load 10-min. no different (p>0.01)
Load pre-walk vs. Load 20-min. no different (p>0.01)
Load pre-walk vs. Load 30-min. no different (p>0.01)
conditions across time revealed no change at the 10-minute [F (1,9) = 0.5, p > 0.01], 20-minute [F (1,9) = 5.2, p > 0.01], or 30-minute [F (1,9) = 1.75, p > 0.01] marks.

Based on planned comparisons the study failed to reject the fifth null hypothesis that a 30-minute walk with an external load does not affect the vertical GRF variable, F2 magnitude, during walking. Comparing the loaded conditions across walk time, no change in F2 was observed at the 10-minute [F (1,9) = 0.001, p > 0.01], 20-minute [F (1,9) = 2.5, p > 0.01], or 30-minute [F (1,9) = 5.25, p > 0.01] marks.

Based on planned comparisons the study failed to reject the sixth null hypothesis that a 30-minute walk with an external load does not affect the average vertical GRF during walking. There was no effect of walk time on the average vertical force at the 10-minute [F (1,9) = 0.05, p > 0.01], 20-minute [F (1,9) = 4.06, p > 0.01, and 30-minute [F (1,9) = 0.78, p > 0.01] marks.

The study failed to reject the seventh null hypothesis that a 30-minute walk with an external load does not affect stance time during walking [F (4,36) = 1.01, p > 0.01.

Finally, the study failed to reject the eighth null hypothesis that a 30-minute walk with an external load does no affect time to F1 during walking [F (4.36) = 1.48, p > 0.01].

Overall, the study revealed no effect of time on selected GRF variables. Mean data for GRF variables are presented in Table 2.

Heart rate (HR) was recorded every three minutes during testing, and it was observed that HR increased during walking with the backpack load for all
Table 2. Mean Data for GRF Variables

<table>
<thead>
<tr>
<th>Conditions</th>
<th>No load pre-walk</th>
<th>Loaded Pre-walk</th>
<th>10-minutes</th>
<th>20-minutes</th>
<th>30-minutes</th>
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<tr>
<td>Backpack load</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>First maximum force (BW)</td>
<td>1.23</td>
<td>1.38**</td>
<td>1.40</td>
<td>1.44</td>
<td>1.40</td>
</tr>
<tr>
<td></td>
<td>(0.10)*</td>
<td>(0.10)</td>
<td>(0.07)</td>
<td>(0.10)</td>
<td>(0.08)</td>
</tr>
<tr>
<td>Second maximum force (BW)</td>
<td>1.17</td>
<td>1.35**</td>
<td>1.35</td>
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<td>1.37</td>
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<tr>
<td></td>
<td>(0.08)</td>
<td>(0.12)</td>
<td>(0.10)</td>
<td>(0.11)</td>
<td>(0.11)</td>
</tr>
<tr>
<td>Average vertical force (BW)</td>
<td>0.82</td>
<td>0.93**</td>
<td>0.93</td>
<td>0.94</td>
<td>0.93</td>
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<td></td>
<td>(0.01)</td>
<td>(0.03)</td>
<td>(0.03)</td>
<td>(0.03)</td>
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<tr>
<td>Stance Time (s)</td>
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<td>0.62</td>
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<td>(0.03)</td>
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<td>Loading Rate (ms)</td>
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<td>(16.54)</td>
<td>(16.46)</td>
<td>(18.22)</td>
<td>(18.01)</td>
<td>(17.27)</td>
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</table>

*Numbers in parentheses are standard deviations

**Indicates significant difference compared to the no load condition

Each force variable is represented in multiples of bodyweight (BW).
subjects (see Figure 5). Mean heart rates for all subjects for each condition are presented in Table 3.

To summarize, F1 magnitude, F2 magnitude, and average vertical force increased significantly when the backpack load was applied. GRF variable magnitudes remained elevated across walk time.
Figure 5. Group Mean Heart Rate (±SE) for each experimental condition.

Table 3. Mean Heart Rates

<table>
<thead>
<tr>
<th>Subject</th>
<th>No Load</th>
<th>Pre-walk</th>
<th>Loaded Pre-walk</th>
<th>Load 10-min.</th>
<th>Load 20-min.</th>
<th>Load 30-min.</th>
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<td>1</td>
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<td>151</td>
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<tr>
<td>Mean</td>
<td>83.1</td>
<td>101.9</td>
<td>113.8</td>
<td>117.2</td>
<td>117.4</td>
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<tr>
<td>Std. Dev.</td>
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<td>16.5</td>
<td>17.3</td>
<td>16.0</td>
<td>15.1</td>
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<tr>
<td>Std. Error</td>
<td>2.9</td>
<td>5.2</td>
<td>5.5</td>
<td>5.1</td>
<td>4.8</td>
<td></td>
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</table>

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CHAPTER 5

DISCUSSION AND RECOMMENDATIONS

The purpose of the study was to investigate the effects of a 30-minute walk on the kinetics of walking with an external load in healthy, young adults. Specifically, the study compared selected vertical GRF parameters prior to, during, and after a moderate walk on a treadmill.

Variations in magnitude and temporal characteristics can be used to describe and understand the body's exposure to forces during load carrying, and can be used to address possible mechanisms for injury. Ground reaction force variables were examined for magnitude and temporal variations relative to body weight during walking with and without load. Significant increases in selected GRF were seen between the unloaded pre-walk and the loaded pre-walk conditions. The observations of the study lead to rejection of the null hypothesis that an external load does not affect the vertical GRF parameters (no-load pre-walk vs. loaded pre-walk) during walking. Furthermore, the observed forces remained elevated relative to no-load walking throughout the 30-minute walk. Therefore, the body was being exposed to greater forces for the entire load-carrying period. The results of the present study are similar to others that have compared GRF during walking with and without a load (Simpson et al., 1988). Based upon the observations of the present study, there was no effect of time on...
selected GRF parameters (see Figure, 2-4). Therefore, the null hypothesis, that a 30-minute walk with an external load does not affect vertical GRF patterns during walking, was not rejected.

A possible explanation for the lack of GRF changes over time during loaded walking is that the experimental conditions were somewhat physiologically demanding but not overly mechanically demanding. It may be that subjects maintained a particular economical gait pattern to optimize physiological cost of walking and, subsequently, let GRF increase. To accommodate to the added load across time, subjects would have changed gait style. It has been observed that physiological cost of locomotion increases as gait style changes from the preferred style (Holt, Hamill, & Andres, 1991; Hamill, Derrick, & Caldwell, 1995).

To observe a change in GRF parameters over walk-time, the experimental conditions might have to be more physiologically and/or mechanically demanding than used in the present study. For example, the 30-minute walk time may not have been long enough to elicit an effect of time on GRF variables. However, the 30-minute walk time was used to represent average campus walking for a college student. Therefore, the results of this study should be applicable to the general college population. It is also possible that walking speed may not have been fast enough to elicit an effect for time (30-minutes). A comfortable walking speed (1.57m/s) was chosen to simulate normal walking conditions. Considering that GRF increases with speed (Munro & Miller, 1987), the mechanical challenge could also have been increased by increasing walk speed. However, this would also have the effect of increasing physiological cost of walking (Epstein et al.,
The lack of change in GRF over time may be evidence that a particular gait pattern is selected for a particular speed in order to optimize oxygen cost of walking.

In a study by Buckley and Young (1999), a significant effect for time was observed after 79 minutes of walking at a speed of 1.78m/s while carrying a 25 kg backpack load. The apparent differences between the results of Buckley and Young and the present study are that subjects walked longer, faster, and carried more load compared to the present study. Future research is needed to determine whether the observed increases in GRF reported by Buckley and Young were due to a greater physiological or mechanical demand. Considering that walk time, speed and load all affect physiological cost of walking, it may be that subjects do not change gait until they approach exhaustion.

Subjects have few choices they can make when walking. Although the neuromuscular-skeletal system consists of many degrees of freedom, the actual movements are constrained by many factors. In the present study, walking speed and load were constraints imposed on the subjects. The results of this study suggest that there is a paradox: If subjects choose to accommodate to the additional load and change gait, physiological cost of walking increases; if subjects choose not to accommodate to the additional load, mechanical cost of walking (e.g. GRF) increases.

It is conjectured that subjects, as a group, did not change gait style in order to remain at an economical gait pattern because the increased GRF was not a threat. Given that GRF magnitudes of 2-3 times body weight are observed during running, the 1.4-1.6 times body weight forces observed in the present
study with loading are not that large. It seems reasonable that subjects, therefore, optimized on physiological parameters rather than mechanical parameters.

In a real life scenario, a person who becomes tired has the choice to change walking speed. In this study walking speed was constrained so that any variations in GRF could be attributed to time rather than to changes in speed. Constraining speed may limit the number of gait choices a person has. For example, in an effort to maintain walking speed, a change in gait can be made by increasing stride frequency (SF) and/or stride length (SL). However, changing SF and/or SL from preferred values would likely result in a greater oxygen consumption which would be less economical (Holt et al., 1991). It has also been established that heart rate (HR) and oxygen uptake (VO₂) increase during walking with a backpack (Holewijn, 1990; Patton et al. 1991). Although VO₂ was not quantified, HR was recorded and it was observed that HR was elevated during walking with the load across time compared to the no load condition for all subjects. Furthermore, increases in RPE were observed for eight of ten subjects across time. This suggests that maintaining a preferred gait pattern to minimize any further increase in oxygen consumption above that due to the load over time might have been more important than accommodating to the additional load.

Variations in the magnitude and temporal characteristics of the vertical GRF parameters during walking were investigated in the study. Comparing the non-loaded condition to the loaded condition, there was significant increase in magnitude relative to body weight for F1, F2, and Favg (p < 0.05). This is important because it demonstrates that the musculoskeletal system was exposed
to increased forces during the load-carrying period. The mathematically predictable response is referred to as a mechanical response to the additional load (Caster & Bates, 1995). In Chapter 1, a mechanical response was defined as no change in the neuromuscular activity pattern with expected force increases or decreases attributed solely to the addition of mass (Caster & Bates). Overall the group exhibited a mechanical response. Evidence for this statement is given by the observed 105N increase in F1 magnitude with load compared to no load walking. Considering that the load was 120N, it is apparent that the subjects made no or little change in gait in response to the added load. It may be that the group did not perceive the backpack load (12.45kg) to be a threat or they did not feel they had a choice physiologically. Changing walking gait by changing either SL or SF would have an expected increase in oxygen consumption; therefore they may have felt it was better to minimize increases in VO$_2$ than to accommodate the additional load.

A study by Voloshin and Wosk (1982) identified the shock wave produced at heal strike during walking as a possible mechanism for injury. Repetitive loading of the body's natural shock absorbers has been linked to joint degeneration and osteoarthritis (Collins & Whittle, 1989; Dickinson et al., 1985; Nigg & Bobbert, 1990; Voloshin & Wosk, 1982). Voloshin and Wosk concluded that diminished shock absorbing capacity was related to low back pain. That is, back pain may be a result of force waves that are not attenuated. The mechanical response demonstrated by the group indicates subjects were not accommodating to the added load and forces increased. It seems reasonable to believe that excess wearing of the body's shock absorbers may take place when
walking with an external load because the demand to attenuate shock is greater. This type of wearing of the joints may not be realized until years later. Further research is needed to test this hypothesis.

It is important to mention that even though the group demonstrated a mechanical response, individual responses varied. Six subjects exhibited a clear mechanical response while four other subjects tended to demonstrate a neuromuscular response to the additional load in that selected force magnitudes (i.e. F1, Favg, & F2) did not increase by a factor equal to the added load when comparing no-load and load conditions. Inspection of subject descriptive characteristics indicated no apparent relationship between response strategy and body weight or gender. Considering this observation, future study needs to be completed in order to understand the different response strategies.

An alternative approach to analyzing GRF data includes normalizing forces to system weight. This allows for detection of relative changes in forces to load. When data were normalized to system weight (body weight + backpack weight) F1, F2 and Favg magnitudes were greatest for the non-loaded condition compared to the loaded conditions. These results resemble results reported by Wiese-Bjornstal and Dufek (1991). Wiese-Bjornstal and Dufek observed a significant decrease in F1 magnitude (p < 0.05) when a backpack load was applied (body weight + 25%). For the present study, the observation that GRF magnitudes relative to system weight were higher during the no load condition is evidence that the group as a whole did not respond using a pure mechanical strategy.
In conclusion, this study rejects the first null hypothesis and it is concluded that carrying an additional load in a backpack has a significant effect on vertical GRF magnitude, specifically increases in magnitudes of F1, F2 and average vertical force. This investigation fails to reject the second hypothesis in that there was no significant effect for time (30-minutes), no significant variation in GRF magnitude either positive or negative across the load-carrying period. The mechanical response to the load may be a result of a limited number of choices for accommodation when speed is constrained.

Recommendations for future research include:

1. The present study examined the effects of carrying an external load for 30 minutes with no significant effect for time. A study to investigate a longer walking time and/or faster walking speed may result in a significant effect for time.

2. Kinematic variables, including hip, knee, and ankle joint analysis, were not examined in the present study. An investigation of the kinematics may help in understanding the effect of carrying a load during walking.

3. Future investigations examining the shock waves produced at heel contact using accelerometers could provide information regarding shock attenuation during loaded conditions compared to non-loaded conditions.

4. A similar study could be conducted using subjects of different age groups. Results may be different for a young age group as well as for an older age group.

5. An investigation measuring oxygen consumption during loaded walking across time would help to understand physiological cost of walking.
APPENDIX I

OFFICE OF SPONSORED PROGRAMS APPROVAL AND
INFORMED CONSENT
DATE: February 15, 2000

TO: Cheryl Cardillo
Kinesiology
M/S 3034

FROM: Dr. Jack Young
Chair, Biomedical Sciences Committee
UNLV Institutional Review Board

RE: Status of Human Subject Protocol Entitled:
"Effects of a Long Duration Hike on the Kinetics of Walking with an External Load"
OSP #504s0100-211

This memorandum is official notification that the above protocol has been approved by the Biomedical Sciences Committee of the Institutional Review Board. This protocol is approved for a period of one year from the date of this notification and work on the project may proceed.

Should the use of human subjects described in this protocol continue beyond a year from the date of this notification, it will be necessary to request an extension.

If you have any questions or require any assistance, please contact the Office of Sponsored Programs at 895-1357.

cc: OSP File
Welcome to the Biomechanics and Motor Control Laboratory. You are invited to participate in a backpacking study. The study involves testing ground reaction forces before and after a long duration (30-minutes) walk on a motor driven treadmill with an external load in a backpack. If you decide to participate, you will be asked to walk on a treadmill at 3.5mph, 0% grade, with an 12.45kg (25lbs.) backpack load. Walking speed of 3.5 mph is approximately equivalent to a 17-minute mile, which is a moderate pace walk. Total walking distance for the study is 1.75 miles. Ground reaction force data will be collected by stepping off the treadmill and walking across a force platform that is situated flush with the floor of the lab. Data will be collected prior to the long duration walk both with and without the backpack load. Additional ground reaction force data will be collected at 10, 20, and 30 minutes from the start of the walk. Each testing session will last 45-60 minutes and will be videotaped for the purpose of analyzing select joint motions. We may wish to use the video tape recording of your movements for educational purposes in the future. However, your identity will not be disclosed. If you would like to give your permission for the use of the video recording for educational purposes (such as classes or conferences), please place you initials by “yes” below. If you do not wish to give permission at this time, please initial by “no”. Video recordings will not be taken for any commercial use.

yes___________________________ no___________________________

The risk to you, the participant, is minimal. This study involves walking on a treadmill with a backpack load similar to walking across campus with books in a backpack. Risk of falling during the long duration walk is minimized using a
treadmill with handrails. There will always be an assistant or the test investigator near you at all times should you fall. You may experience some soreness in the legs or low back muscles for 24 to 48 hours depending on your activity level. Stretching after testing is completed may help to alleviate soreness.

By participating in this study, you may benefit from the knowledge gained about the forces the body endures during walking with an external load. Information gathered from this study may also be beneficial in identifying possible mechanisms for injury and the prevention of such injuries.

All information obtained in connection with this study that can be identified with you will remain confidential. If you choose to participate, you will be assigned a number that will be used for further identification in order to insure your anonymity.

If you choose not to participate you will be excused from the study. You may withdraw from participation in this study at any time, but please inform the experimenter prior to withdrawal. If you have any questions please ask the experimenter. Telephone numbers to call if there are any questions are (702) 895-4672 or (702) 895-4494. For questions regarding rights of Human subjects, you may call the UNLV Office of Sponsored Programs at (702) 895-1357. Thank you for participating in this project.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE BELOW INDICATES YOU HAVE DECIDED TO PARTICIPATE HAVING READ THE INSTRUCTIONS AND INFORMED CONSENT.

Participant name: ___________________________ Date: __________

Participant Signature: ___________________________

Researchers Signature: ___________________________ Date: __________
QUESTIONNAIRE

Participant Initials:_________
Participant Number:_________

Please answer each of the following questions to the best of your knowledge:

SECTION 1: General Information

1. Name:

2. Age:

3. Do you have experience walking on a treadmill?

SECTION 2: Medical History

1. Have you had any recent low back or low extremity injuries? If yes, please explain.
PAR-Q & YOU
(A Questionnaire for People Aged 16 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 16 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Complete answer to your best guess when you answer these questions. Please read the questions carefully and answer each one honestly:

check YES or NO.

YES NO
☑ 1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
☑ 2. Do you feel pain in your chest when you do physical activity?
☑ 3. In the past month, have you had chest pain when you were not doing physical activity?
☑ 4. Do you have your balance because of dizziness or do you ever feel unsteadiness?
☑ 5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
☑ 6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☑ 7. Do you know of any other reason why you should not do physical activity?

If you answered YES to one or more questions
Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a physical exam. Do not start becoming more physically active until your doctor agrees.

- You may be able to do any activity you want—as long as you start slowly and build up gradually. Or, you may need to readjust your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions
If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:
- start becoming much more physically active—build slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal—this is an excellent way to determine your basic fitness so that you can plan the best way for you to live

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this form may be used to help or administer programs.

I have read, understood and completed this questionnaire. Any questions I have had were answered to my full satisfaction.

NAME ____________________________ DATE ____________________________
SIGNATURE: ____________________________ WITNESS: ____________________________

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Société canadienne de physiologie de l'activité physique

Supported by: Health Canada

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APPENDIX II

REPEATED MEASURES ANOVA TABLES
One-way Repeated Measures ANOVA for the dependent variable F1

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<th>Source</th>
<th>Type III Sum of Squares</th>
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<th>Sig.</th>
<th>Noncent. Parameter</th>
<th>Observed Power</th>
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Planned Comparisons for F1

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One-way Repeated Measures ANOVA for the dependent variable F2

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One-way Repeated Measures ANOVA for the dependent variable Favg

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Planned Comparisons for Favg

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One-way Repeated Measures ANOVA for the dependent variable Stance Time

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One-way Repeated Measures ANOVA for the dependent variable Time to F1

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APPENDIX III

GROUP AND INDIVIDUAL SUBJECT INTERPOLATED GRF DATA
Group Interpolated Data for GRF Variables

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<tr>
<th>Backpack Load</th>
<th>No Load Pre-walk</th>
<th>Loaded Pre-walk</th>
<th>10-Minutes</th>
<th>20-Minutes</th>
<th>30-Minutes</th>
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<tr>
<td>F1 (N)</td>
<td>927.3 (221.1)*</td>
<td>1030.4 (216.2)</td>
<td>1047.6 (219)</td>
<td>1077.0 (216.4)</td>
<td>1053.6 (226.5)</td>
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<td>F2 (N)</td>
<td>877.6 (168.8)</td>
<td>1014.3 (172.4)</td>
<td>1015.4 (190.8)</td>
<td>1026.9 (173.6)</td>
<td>1028.6 (184.1)</td>
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<tr>
<td>Favg (N)</td>
<td>619.5 (136.9)</td>
<td>699.5 (140.6)</td>
<td>699.3 (142.8)</td>
<td>706.7 (138.9)</td>
<td>702.8 (142)</td>
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* Numbers in parentheses are standard deviations
Subject 1: Interpolated data for GRF Variables

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Subject 2: GRF Curve

Subject 2: Interpolated data for GRF Variables

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Subject 3: GRF Curve

Subject 3: Interpolated data for GRF Variables

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Subject 4: GRF Curve

Subject 4: Interpolated data for GRF Variables

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Subject 5: GRF Curve

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Subject 6: GRF Curve

Subject 6: Interpolated data for GRF Variables

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Subject 7: GRF Curve

Subject 7: Interpolated data for GRF Variables

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Subject 8: GRF Curve

Subject 8: Interpolated data for GRF Variables

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Subject 9: GRF Curve

Subject 9: Interpolated data for GRF Variables

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Subject 10: GRF Curve

Subject 10: Interpolated data for GRF Variables

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REFERENCES


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Cheryl M. Cardillo

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Degrees:
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University of Nevada, Reno

Thesis Title: Effects of a 30-Minute Walk on Ground Reaction Forces During Walking with an External Load

Thesis Examination Committee:
Chairperson, Dr. John Mercer, Ph.D.
Committee Member, Dr. John Young, Ph.D.
Committee Member, Dr. Richard Tandy, Ph.D.
Graduate Faculty Representative, Dr. Paulette Tandy, Ph.D.