8-31-2005

An Exploration of the Lumbar Loads and Affective Responses to Lumbar Pain on Lower Limb Amputees Who Use a Prosthesis

Tracy Ann Perrotti
University of South Florida

An Exploration of the Lumbar Loads and Affective Responses to Lumbar Pain on Lower Limb Amputees Who Use a Prosthesis

by

Tracy Ann Perrotti

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Biomedical Engineering
Department of Chemical Engineering
College of Engineering
University of South Florida

Major Professor: William E. Lee, Ph.D.
Georgios Stylianides, Ph.D.
Eric Coris, M.D.
Edward Quigley, Ph.D.

Date of Approval:
August 31, 2005

Keywords: biomechanics, accelerometer, spine, survey, back pain

Dedication

To my family for always supporting me in whatever I chose to do.

To my friends who always believed in me and were always there for me.

Acknowledgments

I would like to acknowledge and express my gratitude to Dr. William E. Lee whose insight and scholarly advice has helped me tremendously throughout all the ups and downs of this project.

I would like to thank Dr. Georgios Stylianides who helped me get the project off the ground and was always available to offer help and advice.

Thank you to Dr. Ed Quigley for his support every step of the way and also the use of his equipment.

I want to acknowledge Dr. Eric Coris for being part of my committee and offering advice and support.

Thanks so much to Suzanne Alameda for all the hard work and assistance she has given me, without which I would still be working on this project. I would also like to acknowledge the assistance of Chris Monteparo.

I want to express my gratitude to Courtney Linger for the help she has given me acquiring subjects for this project.

Special thanks to Fred Rakiski, Lisa Downing, Neil Gomes, Rick Hofmann, Barry Trutor, Microstrain Inc., Andre Cournand, Richard Troung and Jaime Fargen.

Table of Contents

List of Tables iv

List of Figures vi

ABSTRACT ix

1.0 Introduction 1
- 1.1 Structure of the Spinal Column 1
- 1.2 Amputees 5
- 1.3 The Gait Cycle 6
- 1.4 Low Back Pain 8
- 1.5 Importance of Study 9
- 1.6 Hypothesis 9
- 1.7 Limitations 9

2.0 Literature Review 10
- 2.1 Prevalence of Back Pain 10
  - 2.1.1 General Population 10
  - 2.1.2 Amputee Population 10
- 2.2 Biomechanics of Low Back Pain 11
- 2.3 Loads on the Spine 17
- 2.4 Accelerometer Use in Biomechanics 19

3.0 Research Design and Experimental Methods 20
- 3.1 Survey 20
  - 3.1.1 Participants 20
  - 3.1.2 Survey Instrument 20
  - 3.1.3 Procedure 21
  - 3.1.4 Data Analysis 21
- 3.2 Accelerometer Study 23
  - 3.2.1 Study Participants 23
    - 3.2.1.1 Power Analysis 24
  - 3.2.2 Instrumentation 24
    - 3.2.2.1 Calibrations 26
  - 3.2.3 Study Protocol 30
  - 3.2.4 Data Analysis 34

4.0 Results 37
4.1 Survey Results.. 37
4.1.1 Amputees 38
4.1.2 Controls 43
4.1.3 Comparison of Amputees and Controls 46
4.2 Accelerometer Results.. 46
4.2.1 Amputees 47
4.2.2 Controls 49
4.2.3 Accelerations 49
4.2.3.1 Walking Trials 50
4.2.3.2 Simulated Leg Length Difference (LLD) Trials .. 61

5.0 Discussion 66
5.1 Survey.. 66
5.2 Accelerometer Study 67

6.0 Conclusions and Recommendations 72

References 74

Bibliography.. 80

Appendices... 82

Appendix 1 Survey of Lower Limb Amputees 83

Appendix 2 Control Group Survey 89

Appendix 3 G-Link Accelerometer Specifications 92

Appendix 4 Information Cover Sheet 93

Appendix 5 Excel Spreadsheet of Survey Results for Amputees............. 95

Appendix 6 Excel Spreadsheet of Survey Results for Controls 110

Appendix 7 Excel Spreadsheet of Survey Results for Amputee Subjects 121

Appendix 8 Excel Spreadsheet of Survey Results for Control Subjects.. 123

Appendix 9 Excel Spreadsheet of Maximum Acceleration Changes 124

Appendix 10 Excel Spreadsheet of Means and Standard Deviations 129

Appendix 11 Excel Spreadsheet of Delta Values................................... 138

List of Tables

Table 2.1 Reasons for Low Back Pain and the Structures Responsible for the Pain 12

Table 2.2 Degenerative Changes of the Intervertebral Disc that Occur with Age 14

Table 3.1 Survey Questions and Rationale 22

Table 3.2 Calibration Readings from the Agile-Link Software 28

Table 3.3 Sample Delta Value Calculations 36

Table 4.1 Summary of Survey Demographics 37

Table 4.2 Medical Condition for Back Pain (Amputees) 39

Table 4.3 Medical Condition for Back Pain (Controls) 43

Table 4.4 Comparison of Survey Results on Back Pain for Amputees versus Controls 46

Table 4.5 Summary of Subject Demographics 47

Table 4.6 Summary of the Information from the Subject Information Sheet (Amputees) 48

Table 4.7 Summary of the Information from the Subject Information Sheet (Controls) 49

Table 4.8 Baseline Accelerations 50

Table 4.9 Average Peak Acceleration for Populations as a Whole 54

Table 4.10 Average Differences between Opposing Legs 58

Table 4.11 Differences between Average Peak Acceleration of Opposing Legs Across Many Steps for Each Subject 59

Table 4.12 Delta Value Analysis 60

Table 4.13 Average Peak Acceleration for Populations as a Whole (LLD Trials) 63

Table 4.14 Average Differences in Average Peak Acceleration for LLD Trials 64

Table 4.15 Delta Value Calculations for the LLD Trials 65

Table 5.1 Average Walking Speed per Trial 70

LIST OF FIGURES

Figure 1.1 Five Regions of the Vertebral Column 2

Figure 1.2 Anterior and Posterior Sections of the Vertebrae 3

Figure 1.3 Intervertebral Disc 4

Figure 1.4 Gait Cycle Events 7

Figure 2.1 Prolapsed Nucleus Pulposus 15

Figure 3.1 G-Link Accelerometer 24

Figure 3.2 Example of the Raw Data from the Agile-Link Program 25

Figure 3.3 Schematic of Foot Switch Set-Up 26

Figure 3.4 Accelerometer Axes 27

Figure 3.5 Baseline Reading of Accelerometer after Calibration 28

Figure 3.6 Pendulum Results for Accelerometer #12 29

Figure 3.7 Accelerometer Attached to L5/S1 Level of Spine 31

Figure 3.8 Simulated Leg Length Difference Set-Up 32

Figure 3.9 Accelerometer's y – axis Aligned with the Gravity Vector and Enclosed in a Plastic Bag 33

Figure 3.10 Determination of Maximum Difference from Agile-Link Output 34

Figure 3.11 Motion Analysis and Accelerometer Results 37

Figure 4.1 Reasons for Non-Prosthesis Use among Amputees 38

Figure 4.2 Nature of Amputee Back Pain 40

Figure 4.3 Intensity of Amputee Back Pain 40

Figure 4.4 Frequency of Amputee Back Pain in the Last Four Weeks 41

Figure 4.5 Level of Phantom Pain among Amputees 42

Figure 4.6 Level of Phantom Sensation among Amputees 42

Figure 4.7 Nature of Back Pain – Controls 44

Figure 4.8 Intensity of Back Pain – Controls 44

Figure 4.9 Frequency of Back Pain in the Last Four Weeks – Controls 45

Figure 4.10 Peak Acceleration for the Normal Walking Speed Trials of Amputees: Amputated vs Non-amputated. Mean and Standard Deviation Error Bars are Shown 51

Figure 4.11 Peak Acceleration for the Normal Walking Speed Trials of Controls: Left vs Right. Mean and Standard Deviation Error Bars are Shown.. 51

Figure 4.12 Peak Acceleration for the Fast Walking Speed Trials of Amputees: Amputated vs Non-amputated. Mean and Standard Deviation Error Bars are Shown 52

Figure 4.13 Peak Acceleration for the Fast Walking Speed Trials of Controls: Left vs Right. Mean and Standard Deviation Error Bars are Shown.. 52

Figure 4.14 Peak Acceleration for the Slow Walking Speed Trials of Amputees: Amputated vs Non-amputated. Mean and Standard Deviation Error Bars are Shown 53

Figure 4.15 Peak Acceleration for the Slow Walking Trials of Controls: Left vs Right. Mean and Standard Deviation Error Bars are Shown 53

Figure 4.16 Average Peak Acceleration for the Normal Walking Speed Trials: Amputees vs Controls. Mean and Standard Deviation Error Bars are Shown... 55

Figure 4.17 Average Peak Acceleration for the Fast Walking Speed Trials: Amputees vs Controls. Mean and Standard Deviation Error Bars are Shown.. 55

Figure 4.18 Average Peak Acceleration for the Slow Walking Speed Trials: Amputees vs Controls. Mean and Standard Deviation Error Bars are Shown.. 56

Figure 4.19 Total Acceleration for Different Walking Speeds........................... 56

Figure 4.20 Differences between Opposing Legs for Different Walking Speeds 59

Figure 4.21 Average Peak Acceleration for the ½ in. Long Trials: Amputees vs Controls. Mean and Standard Deviation Error Bars are Shown.. 61

Figure 4.22 Average Peak Acceleration for the 1 in. Long Trials: Amputees vs Controls. Mean and Standard Deviation Error Bars are Shown.. 62

Figure 4.23 Average Peak Acceleration for the ½ in. Short Trials: Amputees vs Controls. Mean and Standard Deviation Error Bars are Shown.. 62

Figure 4.24 Average Peak Acceleration for the 1 in. Short Trials: Amputees vs Controls. Mean and Standard Deviation Error Bars are Shown.. 63

An Exploration of the Lumbar Loads and Affective Responses to Lumbar Pain on Lower Limb Amputees Who Use a Prosthesis

Tracy Ann Perrotti

ABSTRACT

80% of the American population experiences back pain and it is the most common cause of limited activity in people of age 45 and under. Determining the reasons for back pain and developing new ways to treat it have been extensively researched over the past decade. However, very little research has been done on low back pain of amputees.

There are four million existing amputees living in America and 250,000 people become new amputees each year. 70% of this group is lower limb amputees and a large number use a prosthesis of some kind to aid in the functions of daily living (Amputation and Limb Deficiency). Not all amputees use a prosthesis because of pain involved, aesthetics, and cost.

In order to increase the use of prosthetics among amputees, the reasons why they do not use them must be fully understood. With this knowledge better prosthetic designs can be created. The purpose of this study is to first determine the prevalence of back pain among lower limb amputees who use a prosthesis and then to quantify the accelerations in the spine of this group and compare it to subjects who are not amputees. The findings of this study will be used to determine if back pain is a common complaint, if it interferes with daily activities, and if the use of a prosthesis causes abnormal loads in the spine of amputees.

A cross-sectional descriptive survey was created and distributed to lower limb amputees who use a prosthesis and to a control group. In addition to the survey, several subjects were recruited to wear an accelerometer located over the L5-S1 vertebrae and walk at several speeds down a pathway. A maximum acceleration was determined for each step as well as the difference in acceleration between opposing legs. Also measured was the effect of a leg length discrepancy (LLD) on accelerations and back pain.

As a result of this research it was found that a high percentage of amputees experience back pain and the prevalence is higher than that of controls. It has shown that there is a difference between the acceleration patterns of amputees and non-amputees, but further research is needed to show that this difference is what causes the higher prevalence of back pain. The trend of side dominance and its increase with increased walking speed for amputees has been shown as well as a general population trend of increased acceleration of the spine with increased speed. In relation to walking speed, the study has also shown that the perception of speed among amputees is slower than that of controls. This study has also supported the notion that a difference in leg length could cause low back pain.

1.0 Introduction

1.1 Structure of the Spinal Column

"The spinal column combines an intricate architectural arrangement of bone, muscle, and soft tissue to form a structure of mechanical and physiological significance. Not only does the spinal column serve to protect the spinal cord, but it also transmits, attenuates and distributes the static and dynamic forces associated with daily activities." [Keller, 2000]

The spinal column is a series of vertebrae connected to one another by joints and ligaments. It has a considerable degree of flexibility and strength that allows it to support the head and neck, transmit the weight of the body to the lower limbs, aid in locomotion, protect the spinal cord, and aid in respiration. Therefore, it is continually subjected to a variety of forces.

There are five main regions of the spinal column based on differences in curvature and important features (Figure 1.1). The cervical vertebrae consist of the first seven vertebrae including the atlas and the axis. The next region is the thoracic region, which consists of twelve vertebrae. The lumbar region is next with five vertebrae. It is here where most pain exists. The sacral region is next. It consists of the sacrum, which are five fused vertebrae. The last region is the coccy formed by the rudimentary vertebrae.

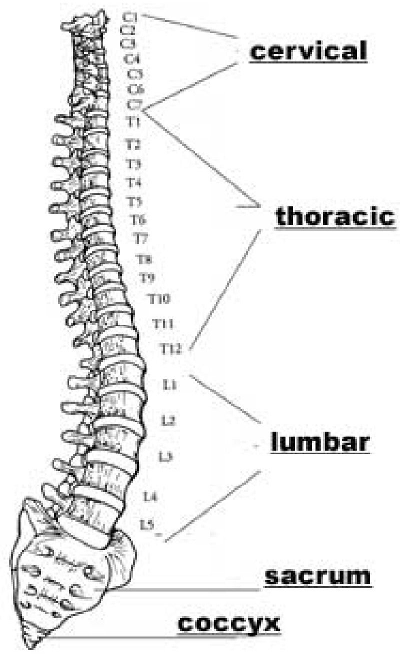

Figure 1.1 Five Regions of the Vertebral Column.
[www.courses.vcu.edu/DANC 291-003/]

Each vertebra consists of two portions: the anterior and posterior (Figure1.2). The vertebral body is the bulkier, anterior portion of the vertebra. The structure of the vertebral body is such that it can bear mostly compressive loads. It is connected to other vertebral bodies by the intervertebral disc. This part of the vertebra plays a role in weight bearing, thus this is where the loads transmitted by the body will be greatest. The disc generally undergoes compressive, bending and torsional loads throughout daily activities. When unloaded, its intrinsic pressure is 10N per square centimeter [Nordin, 2001] but under compression the pressure becomes 1.5 times the externally applied load per unit area.

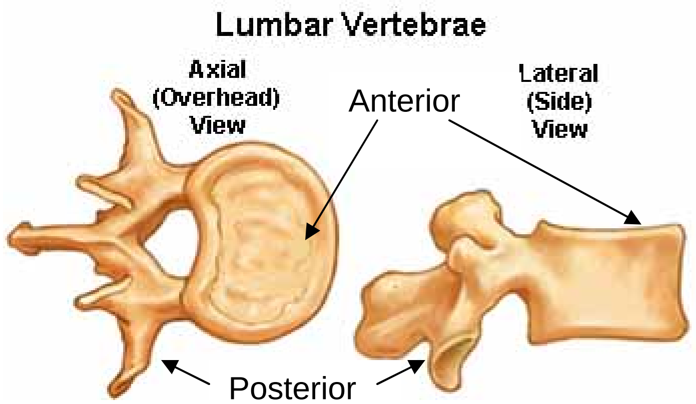

Figure 1.2 Anterior and Posterior Sections of the Vertebrae.
[Bridwell, 2005]

The posterior portion of the vertebrae, which includes the vertebral arch, is where most of the movement of the spine originates. The vertebral arch plays a role in protecting the spinal cord and consists of pedicles, laminae and the vertebral foramen. Also included in the posterior portion are the intervertebral joints, the transverse and spinous processes and various ligaments. The intervertebral joints are formed by the facets, which also act as the site of attachment for the muscles and ligaments. The orientation of the facets is what determines the motion of the spinal segment. They also play an important role in resisting shear forces.

There are many ligaments and muscles that support and aid the spinal column in its functions. The ligaments play an important role in the intrinsic stability of the spine while the muscles are active in producing its motion [Nordin, 2001].

The lumbar vertebrae consist of a larger body than other vertebrae with the fifth lumbar vertebrae being the largest and heaviest. This is consistent with its role in transmitting weight to the sacrum. Shearing stress at the intervertebral disc at this level is at its highest and the orientation of the facets helps minimize this stress. The facets are oriented at right angles to the transverse plane and at 45° angles to the frontal plane. This also allows for flexion, extension and lateral flexion but almost no rotation.

The intervertebral disc plays an important load-bearing role and degeneration of the disc is the source of many low back problems. Its structure consisting of an inner and outer portion is well suited for its role (Figure 1.3).

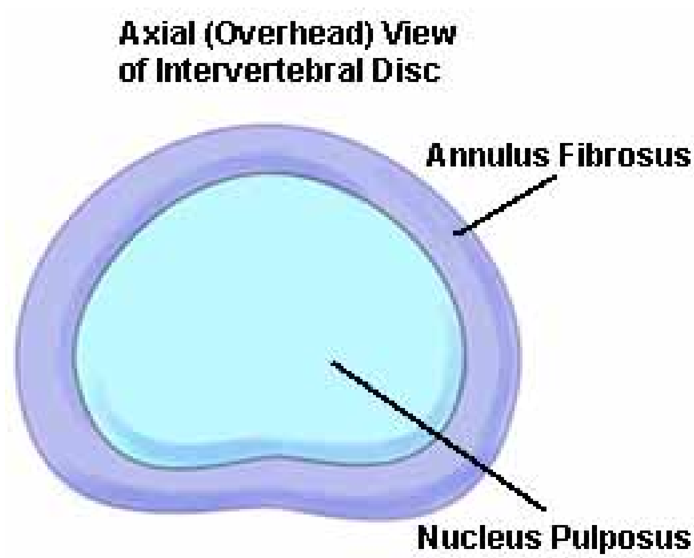

Figure 1.3 Intervertebral Disc. [Richeimer, 2005]

The nucleus pulposus is the gel-like inner portion of the disc. It consists of 70-90% water and acts to dissipate and transfer loads between vertebrae. The tougher outer covering is the annulus fibrosus. It consists of fibrocartilage in a criss-cross arrangement that helps withstand high bending and torsional loads. Degenerative changes, excessive loading and cyclic loading can cause weakening of the fibers and extrusion of the inner nucleus. The extrusion of the nucleus impinges on surrounding nerves and can cause pain.

1.2 Amputees

There are four million existing amputees living in America and 250,000 people become new amputees each year. Seventy percent of this group is lower limb amputees and a large number use a prosthesis of some kind to aid in the functions of daily living [Amputation and Limb Deficiency, 2003]. Factors such as pain, aesthetics and cost limit the number of amputees who use a prosthesis. Much research has been done to improve the aesthetics of prostheses and funding is available to help offset the cost. The pain aspect has been looked at from several angles including phantom pain, phantom sensation, residual limb pain and physical pain from the prosthesis itself. The prevalence of back pain and its effect on prosthesis use is not well understood. It is estimated that by the year 2020 there will be a 47% increase in the number of people with amputations and using a prosthesis [Prosthetics-Orthotics.net, 2004]. With this increased use, understanding pain associated with a prosthesis is of great importance.

People become amputees for many reasons including congenital defects, trauma, cancer, diabetes and vascular disease. In the United States, the majority (70%) of lower limb amputees are a result of disease followed by trauma (22%), congenital defects (4%) and tumors (4%) [Albert Einstein Healthcare Network]. The cause of the amputation and the level of amputation have an important effect on the use of a prosthesis. If the remaining limb is long and the joints are preserved it is easier to fit and use a prosthesis. The energy required to walk also decreases with longer residual limbs [Albert Einstein Healthcare Network].

Lower limb amputees can be classified into five categories: foot, transtibial (below the knee), knee disarticulation (knee joint), transfemoral(above the knee) and hip disarticulation (hip joint).

1.3 The Gait Cycle

The gait cycle begins when one foot touches the ground and ends when that same foot touches the ground again. It is divided into two phases: stance and swing. During stance phase the foot is in contact with ground. This occupies 60% of the gait cycle. During swing phase the foot is not in contact with ground and this occupies the other 40% of the cycle.

Stance phase can be further divided into double limb and single limb support. During double limb support both feet are in contact with the ground whereas during single limb support only one foot is in contact with the ground. One complete gait cycle consists of three periods of double support and two periods of single limb support.

The gait cycle begins when either the left or right heel contacts the ground. For this discussion, the cycle will begin with right heel contact comprising the first phase of double limb support and the initiation of right stance phase. This is followed by left toe off which begins the first period of single limb support particularly right single support. Next the left heel will contact the ground beginning the second phase of double limb support. Left single limb support is initiated when the right toe leaves the ground. This also begins right swing phase that lasts until right heel contact when right stance phase begins again. This is where the cycle ends. Figure 1.4 is a representation of the gait cycle.

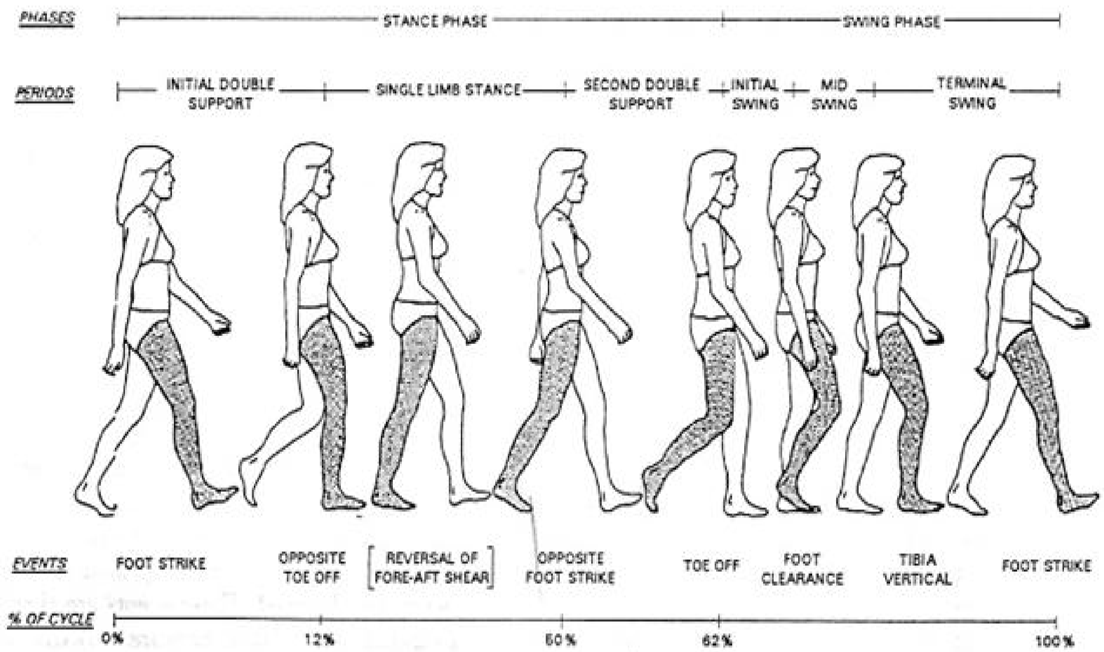

Figure 1.4 Gait Cycle Events. [www.me.dal.ca/~dp_03_8/rev2.html]

There is an identifiable pattern that can be classified as “normal gait” which includes the actions above. In order to walk a person must be able to accomplish four things as outlined by Michael Whittle :

1. Each leg in turn must be able to support the body weight without collapsing.
2. Balance must be maintained, either statically or dynamically, during single leg stance.

3. The swinging leg must be able to advance to a position where it can take over the supporting role.
4. Sufficient power must be provided to make the necessary limb movements and to advance the trunk.

In normal gait there is no apparent difficulty in accomplishing this. There is also minimal energy consumption. When any one of these things cannot be accomplished then locomotion is impossible.

In pathological gait, an abnormal pattern is created so as to accomplish the four requirements above. This abnormal gait can be a result of a disorder in the brain, spinal cord, nerves, muscles, joints, or skeleton or as a result of pain. Any deviation from normal gait increases energy expenditure as well as the changes the loading on muscles, ligaments and joints.

1.4 Low Back Pain

Low back pain is defined as “sudden, sharp, persistent or dull pain felt below the waist” [Fessler, 2002]. Over half of the American population suffers from either chronic or acute back pain and reasons for the pain can include muscle strain, spinal stenosis, arthritis, spinal tumors, spinal infection, spondylolisthesis, and vertebral fractures. More often than not the pain is classified as “non-specific” meaning the exact reasons for it are unknown. It is important to understand why back pain occurs in order to help treat people who suffer from it. Presently, treatment options include rest, medication, physical therapy, and surgery.

1.5 Importance of Study

With the increase in sophistication and design of lower limb prosthetics more amputees are able to lead an active lifestyle. With the increase in activity, the prevalence of back pain could also increase. It will be important to determine if back pain is a significant complaint among prosthesis users and to determine the reasons for the pain. Information about loading of the spine and abnormalities in gait with relation to back pain will aid in designing a better prosthesis.

1.6 Hypothesis

Based on previous research and understanding, it is hypothesized that back pain will exist among amputees and that it will be a significant limiting factor in using a prosthesis. It is hypothesized that the prevalence of back pain will be higher among amputees than among the general population and that it will be more severe in intensity and occur more often.

It is also hypothesized that the accelerations in the lumbar spine of amputees who use a prosthesis will differ from that of able-bodied subjects. The amputees will have a higher average acceleration and will exhibit a larger difference between opposing legs.

1.7 Limitations

This study was limited in that an insufficient number of subjects volunteered for human trials. Also the accelerometer could not be attached directly to the spine but had to be taped to the subject's skin.

2.0 Literature Review

2.1 Prevalence of Back Pain

2.1.1 General Population

Eighty-eight percent of the American population experiences back pain and it is the most common cause of limited activity in people age 45 and under [Nachemson, 1971]. The majority of people affected are between the ages of 20 to 55 with incidences starting in the 20's and reaching a maximum by age 40. Ninety percent of people report that the pain subsides within two months but the other 10% deals with the pain longer. Due to back pain 10 million people take off work daily and an estimated $20-$50 million is spent annually on back pain. Determining the reasons for back pain and developing new ways to treat it have been extensively researched over the past decade. However, very little research has been done on low back pain of amputees.

2.1.2 Amputee Population

The prevalence of back pain among amputees has not been researched extensively. Several groups have reported that 50% of lower limb amputees experience persistent and bothersome back pain [Ehde, Lee, Smith]. A University of Sterling study from the United Kingdom reported that 75% of the sample surveyed attributed prosthesis use to back or hip pain. Smith et al. reported back pain as more bothersome than phantom limb pain but less bothersome than residual limb pain. They reported that 71% of those surveyed experienced back pain and that persons with above the knee amputations were significantly more likely to experience back pain and with greater intensity than below the knee amputees.

Ehde et al. found that only 52% of those sampled experienced back pain. 43% of which rated the back pain intensity in the mild range and one quarter of the group said that the pain severely interfered with daily activities. In contrast to Smith's study, Ehde found no significant differences between above the knee and below the knee amputees.

2.2 Biomechanics of Low Back Pain

Eighty percent of individuals with low back pain are said to suffer from "non-specific low back pain" [Nachemson, 1971]. This is due to the fact that the exact reasons for the pain are unknown. Some common causes of low back pain are muscle strain, injury to the back, overuse, muscle disorders, pressure on the nerve root and poor posture. Some typical events that occur relating to these causes are presence of lumbar subluxations, improper lifting techniques, auto accidents, prolonged sitting, prolonged use of non-ergonomically designed equipment, excessive repetitive torsal motions, fallen foot arches and other foot abnormalities, and physical inactivity [Causes of Low Back Pain]. It has been repeatedly demonstrated that more than 50% of patients say that their pain originated in connection with a mechanical task and the pain is often attributed to lumbar disc herniation or a dysfunctional intervertebral disc [Nachemson, 1971]. Other structures also identified as possible sources of lumbar pain include lumbar facet joints and joint capsules, lumbar and pelvic muscles and ligaments, lumbar and sacral nerves and sacroiliac joints. Instability of the spine and pathological features can produce abnormal motion patterns and forces that can play a major role in low back pain. Table 2.1 summarizes the reasons for low back pain and structures that can be responsible for the pain.

Table 2.1 Reasons for Low Back Pain and the Structures Responsible for the Pain.

Reasons for Low Back Pain	Muscle Strain Injury to the Back Overuse Muscle Disorders Pressure on the Nerve Root Poor Posture
Structures Responsible for the Pain	Intervertebral Disc Lumbar Facet Joints and Joint Capsules Lumbar and Pelvic Muscles and Ligaments Lumbar and Sacral Nerves Sacroiliac Joints

In a discussion of low back pain the structures of utmost importance are the intervertebral disk, surrounding ligaments and apophyseal joints. These are considered the load bearing structures of the spine and the intervertebral disc is said to resist most of the compressive force. The intervertebral disc carries approximately 80% of the load across two lumbar vertebrae. The apophyseal joints and laminae carry the other 20%. The disc's low capacity for remodeling and repair leave it vulnerable to the fatigue failure that has been associated with mechanical failure of the spine. As a result of mechanical failures, degenerative changes take place resulting in pain [Dolan].

The intervertebral discs of the lumbar spine are the largest and thickest of all the discs in the spinal column. Gilad and Nissan[1986] observed lumbar disc heights of 10.6mm +/- 1.4 mm anterior and 7.0 +/- 1.1mm posterior while Lin et. Al observed an average range of disc thickness between 7.1 mm and 12.5 mm. This is compared to the average cervical disc height of 5.2 mm +/- 0.6 mm anterior and 3.2 mm +/- 0.7 mm posterior observed by Gilad and Nissan. The area of the discs also varies greatly. Yamada found the average cross sectional area of cervical discs to be 305 mm^2 compared to 1055 mm^2 for lumbar discs. This increased size allows the lumbar disc to resist higher compressional loads.

The intervertebral disc undergoes the most dramatic age-related changes in comparison to other musculoskeletal tissues [Buckwalter et al., 1993]. The degenerative changes that occur can lead to less mobility, reduced biomechanical properties and spinal stenosis. For example, a newborn's disc contains 88% water while a 70 year old's disc contains only 64%water. This reduction in water causes the disc to harden. It loses its ability to absorb loads and redistribute pressure. Table 2.2 includes some of the degenerative changes that occur during adulthood and in the elderly [Farfan, 1973; Burkart and Beresford, 1979; Koeller et al., 1986; Buckwalter, 1995].

As a result of these degenerative changes the disc loses its ability to keep vertebrae positioned correctly as well as maintain spacing and attachment. The degenerative and aged disc bulges more and thus increases the probability of disc herniation [Lin et al., 1978].

Table 2.2 Degenerative Changes of the Intervertebral Disc that Occur with Age.

Age	Degenerative Changes
Adulthood	Peripheral blood vessels disappear leading to less nutrition. Fissures and cracks appear in the disc. Nucleus becomes firmer. Water concentration decreases, decreasing disc height. Cartilage and end plates become thinner.
Elderly	Water content continues to decrease. Prominent fissures and clefts appear in the central region of the disc. Collagen fibers in the nucleus become less organized. General tissue degeneration, including increased collagen cross-linking.

Disc herniation is 15 times more likely to occur in the lumbar spine than in the cervical spine and thus is one of the most common causes of low back pain [Freedman, 2002]. There are typically two mechanisms by which it can occur. When a very large, sudden compressive force is delivered over the lumbar spine like that which would occur during a fall or lifting a large load, injury can occur.

This is most likely to happen when the spine is flexed and/or rotated. The second mechanism is a combination of repeated low compressive forces and flexed posture. Mechanical factors and repetitive lifting especially on a flexed or twisted spine can often disrupt the structure of the annulus fibrosus of the intervertebral disc. When the spine is flexed the annulus is stretched and thus thinner on the posterior side. Once the annulus is structurally compromised the risk of disc herniation increases as the nucleus pulposus is forced posterior. Under compression the disc acts like a hydrostatic cushion and can evenly distribute the pressure and loads. But the nucleus pulposus is only slightly compressible and bulges laterally under compression [Nordin, 2001]. The annular fibers withstand a tensile stress that has been estimated as four to five times the applied load. If the fibers have been compromised, the inner nucleus pulposus eventually begins to protrude through the weakest part of the outer ring. The prolapsed nucleus pulposus irritates surrounding nerve roots and causes pain (Figure 2.1).

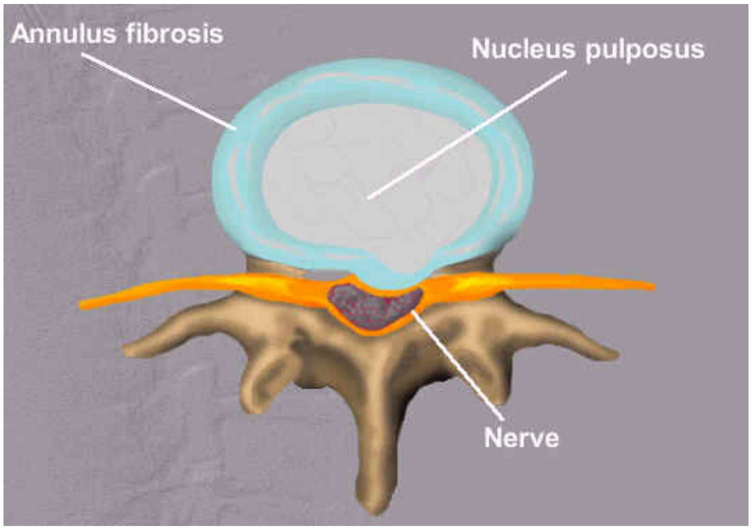

Figure 2.1 Prolapsed Nucleus Pulposus. [Regan, 2005]

The apophysial joints are formed by the articulation between opposing facet surfaces. They are often referred to as facet joints. There are 24 of these synovial joints in the vertebral column and they play a role in limiting rotation about the intervertebral disc. It has been well documented that these joints cause pain and although the exact mechanism is unknown one of the best guesses is hyperextension of the joint [Thomas 2002]. This causes the capsule surrounding the joint to stretch. Extensive twisting or rotating of the spine can also injure these joints. If injuries are left undiagnosed they can later lead to degenerative arthritis, which will impinge upon the nerve root and cause pain.

One possible factor that researchers have looked into and that may be the cause of amputee back pain is a leg length discrepancy (LLD). A leg length discrepancy is any difference in the length of a person's legs. Several authors have implicated LLD as a possible source of back pain among the general population [White, 2004; Lee, 2003; Giles, 1981; Gofton, 1985]. They showed that back symptoms correlated significantly with lateral trunk asymmetry and altered kinematics of the spine caused by LLD. The degree of LLD that causes back pain symptoms is still under debate. Soukka et al [1991] found that a LLD of 10 to 20 mm did not increase the incidence of low back pain. Gross [1978] believes that a LLD of 30 mm or more would be necessary to produce clinically important effects. Fisk and Naigent on the other hand found a 6% incidence of patients with low back pain and a LLD of only 12.5 mm.

The effect of LLD on amputees has not been studied extensively. Frieberg found that 34% of lower limb amputees had a LLD of greater than 20 mm and that in 79% of these cases the prosthesis was shorter than the sound limb. Both he and Burke were able to significantly correlate back symptoms in these individuals with lateral trunk asymmetry caused by the LLD.

2.3 Loads on the Spine

Spinal loads are produced by body weight, muscle activity; pre-stress exerted by the ligaments and externally applied loads [Nordin, 2001]. There have been studies conducted on the loads of the lumbar spine in an attempt to relate them to low back pain and there is evidence that the severity and frequency of low back pain can be related to heavy loading of the spine [Cromwell, 1989]. Mechanical stress factors have also been related to the occurrence of low back syndromes [Anderson, 1977]. A majority of studies related to loading of the spine have focused on loads while performing mechanical tasks especially lifting. Few studies have focused on loading just during walking and even fewer have studied the loads for amputees during walking. The purpose of this study will be to quantify the loads for amputees and relate it to the normal population.

One of the main functions of the muscles of the trunk during walking is to stabilize the torso over the pelvis and lower extremities. This muscle activity is minimized when the segments of the spine are well aligned [Nordin, 2001]. The activation of muscles and thus subsequent accelerations in the spine, result in cyclic spinal loads [Callaghan, 1999]. This fluctuation in loading is a result of shifts in body weight with the greatest moment occurring about the pelvis latero-lateral axis [Goh, 1998].

Several methods have been used to determine the loads in the spine. Since the activation of the trunk muscles has been seen as the main source of the compressive force, measurements of the myoelectric activity of these muscles is one of the more popular techniques used. Cromwell [1989] used myoelectric signals and biomechanical models to show that the peak muscle activity occurred in the erector spinae muscles just after left heel strike. The largest forces measured in these muscles ranged from 45-65 N. These muscles are used to resist the forward motion of the body during walking and thus result in a spinal compression force of 1.2 times the body weight.

Other groups have found similar results using other methods. Cappozzo[1984] used a mechanical model based on 3-D kinematic information from the upper torso and also found that the trunk extensor muscles produced the largest moment and that it was about the latero-lateral axis. He found that the compression load was between 1.0 and 2.5 times the body weight at the L3/L4 level. Khoo [1995] used a biomechanical model developed using body segment parameters from Vicon and intra abdominal pressures. He found that the peak loads occurred during heel strike and toe-off and were measured as 1.45 and 2.07 times body weight at the L5/S1 level. Goh [1998] used a method similar to Khoo. Although looking at the effects of backpack loads on the forces in the spine his control group was that of walking with no load. He found that the mean force also occurring at the L5/S1 level was 1.50 times body weight.

2.4 Accelerometer Use in Biomechanics

Accelerometers have been used extensively in biomechanics. The majority of applications include vibration analysis. Accelerometers have been used to asses whole body vibrations while in cars, wheelchairs, sports activities and in work related situations. They are also used as measures of trunk accelerations, physical strain, activity levels and muscle power.

Accelerometers have been proven reliable in gait analysis [Auvinet, 2001; Yack, 1993; Bouten; 1994; Moe-Nilssen, 1998]. Henriksen et al. [2003] used a triaxial accelerometer mounted on the lumbar spine to determine such gait events as mean acceleration, step length, stride length and cadence. The results were that all measurements showed high intraclass correlation coefficients. Smidt et al. [1971] used accelerometers to analyze several types of walking and concluded that a harmonic ratio could be used to determine the smoothness of gait. Robinson et al. conducted a similar study on below the knee amputees. Mansfield and Lyons [2003] found that accelerometers were valid sensors for the detection of heel contact events during functional electrical stimulation assisted walking. They used a dual axis accelerometer placed over the lumbar spine to find a 150 ms delay between heel contact and negative-positive change in acceleration.

3.0 Research Design and Experimental Methods

3.1 Survey

3.1.1 Participants

Participants for the amputee survey were recruited from West Coast Brace and Limb (local prosthesis distributor), John Knox Village (a retirement community), and Shands Rehabilitation Hospital in Gainesville, Florida. The survey was also available online at several amputee related websites. The inclusion criteria for the survey were that the participant be a lower limb amputee, at least 18 years of age, and able to read and write English. Participants for the control survey (non-amputees) were recruited from the Tampa Bay area. Inclusion criteria included: at least 18 years of age and able to read and write English. The University of South Florida's Division of Research Compliance approved the study.

3.1.2 Survey Instrument

A cross-sectional descriptive survey [Appendix 1] was created to evaluate the prevalence of back pain among lower limb prosthesis users. The survey consisted of 40 open and close-ended questions that evaluated the subject's physical health, history and satisfaction with their condition. Questions are grouped into three main categories: demographic and amputation history, prosthesis use and satisfaction, and frequency and intensity of pain. A table of the questions and rationale for why they were asked are included in Table 3.1.

The control group survey (Appendix 2) consisted of 19 open and closed ended questions. This survey was a modification of the cross-sectional descriptive survey used for the amputees. Differences included the omission of questions regarding the amputation, prosthesis and amputee related pain. Several questions were modified to remain relevant to non-amputee subjects.

3.1.3 Procedure

Surveys were distributed via contacts at the various locations mentioned above to maintain anonymity. Each interested participant was given an information cover sheet [Appendix 3] to explain what the survey was for and who was conducting it. The amputee survey was also made available online at several amputee related websites. A link was posted on those websites and interested participants could complete and submit the survey online.

3.1.4 Data Analysis

Data was collected and an Excel spreadsheet was created for both surveys. The data was imported into SAS and several procedures were run. From these procedures the frequency of each variable was determined as well as if there was a correlation with back pain and age, BMI, time since amputation, satisfaction with prosthesis, hip pain, gender and medications.

Table 3.1 Survey Questions and Rationale.

	Survey Question	Rationale
Demographic and Amputation History	Age, weight, height, gender	Correlation to pain, grouping
	Present Occupation	Pain effects work status, job is risk factor
	Taking medication	Medication related to pain
	Type of prosthesis	Effects on pain
	Side of the body prosthesis is located	Effects on pain
	Use any other prosthesis	Effects on pain
	Manufacturer of prosthesis	Differences among types of prosthesis
	Weight of prosthesis	Effects on pain
	Date of amputation	Pain affected by time since amputation
	Date of fitting	Pain affected by time using a prosthesis
Prosthesis Use and Satisfaction	% of time using prosthesis	Effects on pain, does pain effect this time
	Longest time able to stand	Effects from pain
	Reason for amputation	Effect on pain
	Activity level before prosthesis	Change due to pain
	Change in activity level	
	Activity level now	Effect on pain
	Participation in activities(# days a week)	Effect on pain
	Satisfaction with prosthesis	Effect use of prosthesis
	Satisfaction with life before prosthesis	Different since becoming an amputee
	Satisfaction with life after prosthesis	General
	Main reason for disuse of prosthesis	Want to know if pain is a factor
	Any other assist device	Effect pain
Frequency and Intensity of Pain	Experience back pain	What survey is for
	Medical condition other than amputation that could cause pain	May have pain but not due to prosthesis
	Level of back pain	Similarities/differences among group
	Location of back pain	Similarities/differences among group
	Nature of back pain	Similarities/differences among group
	Frequency of pain in last 4 weeks	Is pain recent
	Pain interfere with certain activities	How bothersome the pain is
	Seeing a specialist	Doing anything about pain and is it helpful

Table 3.1 (continued)

	Experience hip pain	Evaluate other types of pain experienced by amputees, any correlation between pains
	Level of hip pain	Comparison to back pain
	Experience phantom pain	Evaluate other types of pain experienced by amputees, any correlation between pains
	Level of phantom pain	Comparison to back pain
	Experience phantom sensation	Evaluate other types of pain experienced by amputees, any correlation between pains
	Level of phantom sensation	Comparison to back pain
	Pain in non-amputated leg	Evaluate other types of pain experienced by amputees, any correlation between pains

3.2 Accelerometer Study

3.2.1 Study Participants

Participants for the accelerometer study were recruited from West Coast Brace and Limb and the University of South Florida. Inclusion criteria for amputees included lower limb amputee, no prior history of back problems, able to walk unassisted, fluent in English and at least 18 years of age. Inclusion criteria for the control group included no prior history of back problems, able to walk unassisted, fluent in English and at least 18 years of age. The University of South Florida's Division of Research Compliance approved the study and all participants gave written informed consent.

3.2.1.1 Power Analysis

A power analysis was performed to determine the appropriate number of subjects needed for this study. The following equation and inputs were used:

$$n = 2\left[\frac{(\alpha + \beta)\sigma}{\Delta}\right]^2$$

$$\alpha + \beta = 2.80$$

$$\sigma = 20\%$$

$$\Delta = 25\%$$

Based on the above equation the sample size needed for the accelerometer study is 10.

3.2.2 Instrumentation

The acceleration of the lumbar spine of participants in the accelerometer study was determined from the direct acceleration measurements using a 3-D accelerometer (Figure 3.1).

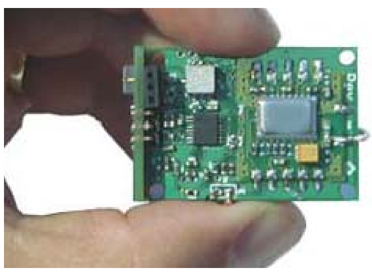

Figure 3.1 G-Link Accelerometer [www.microstrain.com, 2005].

The G-Link Wireless Accelerometer System from MicroStrain was used. It consisted of a high speed, triaxial accelerometer with a +/- 10 G acceleration range and a base station transceiver that can trigger data collection from 30 meters away and transmit data continuously. The accelerometer weighs

9.8715 grams. Appendix 4 contains the specifications for the G-Link wireless accelerometer system. Anti-aliasing filters are deployed by the manufacturer and consist of a two pole active filter with a -3 db frequency of 500 Hz and -40 db decade roll off.

The Agile-Link program was used to record the output given by the accelerometers; graph acceleration versus sweeps and created an Excel spreadsheet file containing the raw data for a specified channel. A graph of acceleration versus time was then created. The x-axis time scale (sec) was determined by dividing the sweep value by the sweep rate (829 sweeps/sec). Figure 3.2 is an example of the raw data obtained from the Agile-Link software.

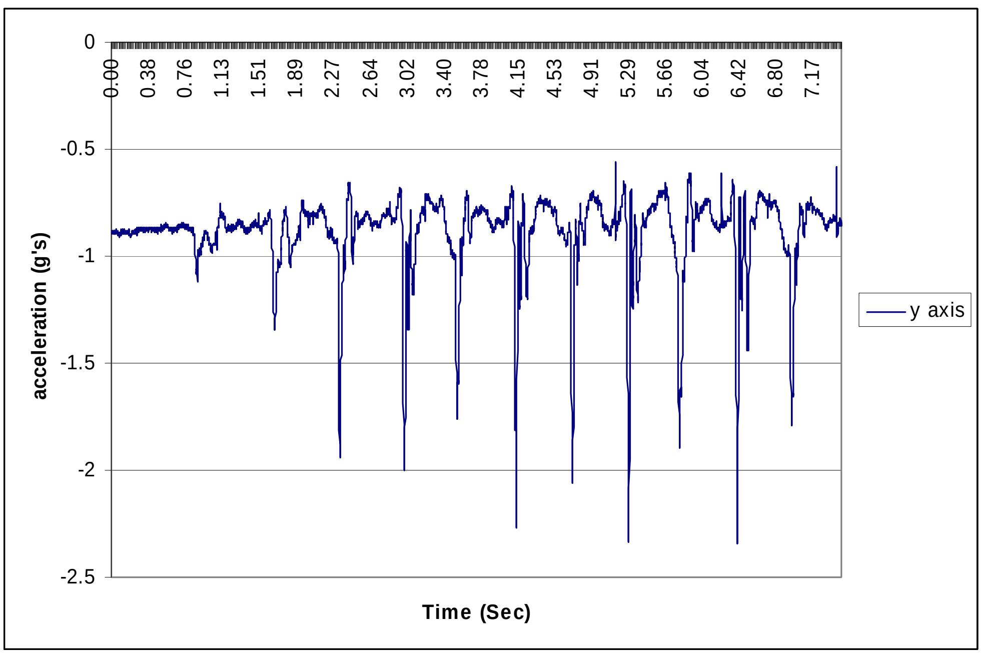

Figure 3.2 Example of the Raw Data from the Agile-Link Program.

In addition to acceleration data, heel strike data was also collected using National Instruments A/D converter (DAQCard-6062E), breakout box(SCB-68), a voltage divider, comparator circuit and force sensing resistors(FSR). The comparator circuit was built to read an input voltage from one FSR and trigger the LabVIEW program, created to record the voltage from the FSR's used as footswitches. A schematic of the set-up can be seen in Figure 3.3.

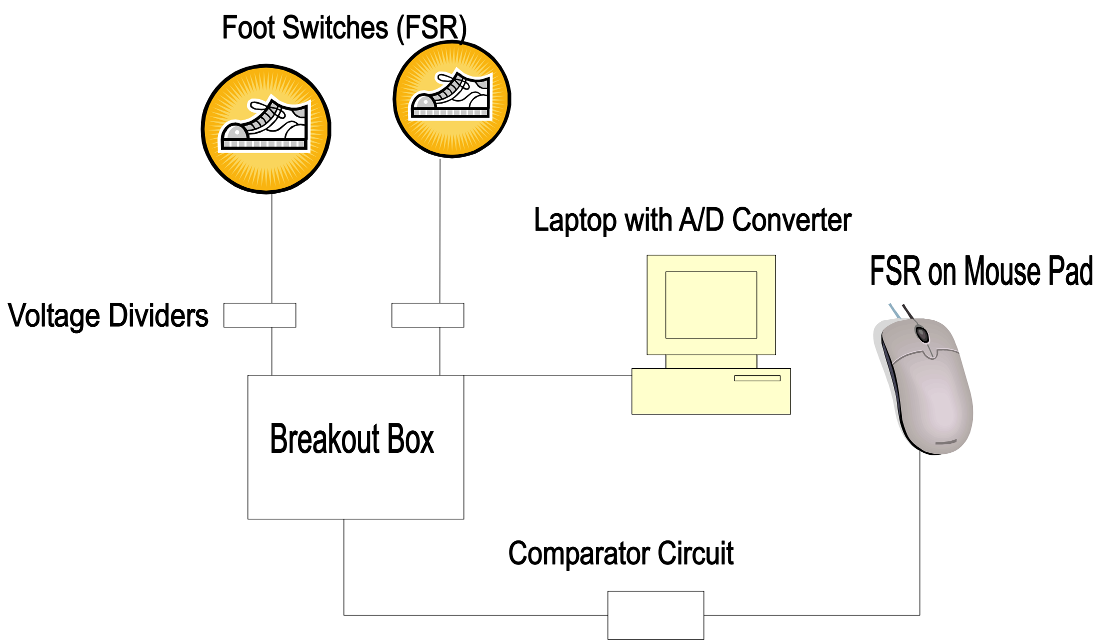

Figure 3.3 Schematic of Foot Switch Set-Up.

3.2.2.1 Calibrations

Two calibrations were performed. The first, as recommended by the manufacturer, calibrated the accelerometers in earth's gravity field. The Agile-Link software is equipped with a plug-in that calibrates the three channels of the accelerometer. The procedure involved rotating the accelerometer about a sensitive axis and looking at the high and low values. From there a gain and offset were automatically calculated by the G-Link calibration plug-in. This plug-in allowed the output of the accelerometer to be given in units of gravitational acceleration (g). This procedure was conducted for each of the three axes shown in Figure 3.4. The results of the calibration are shown in Table 3.2. Figure 3.5 shows a baseline reading of the accelerometer after calibration and aligned so that the y-axis was parallel with the gravity vector.

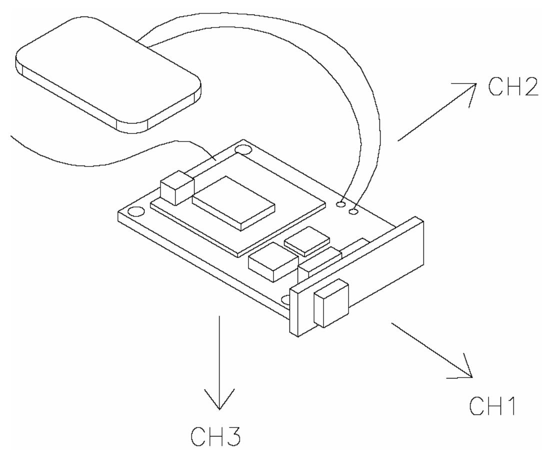

Figure 3.4 Accelerometer Axes. [www.microstrain.com, 2005]

Table 3.2 Calibration Readings from the Agile-Link Software.

Accelerometer	Channel	Gain	Offset
#12	1	208	1956
	2	205	1993
	3	208	1881
#15	1	196	2035
	2	202	1909
	3	203	2098

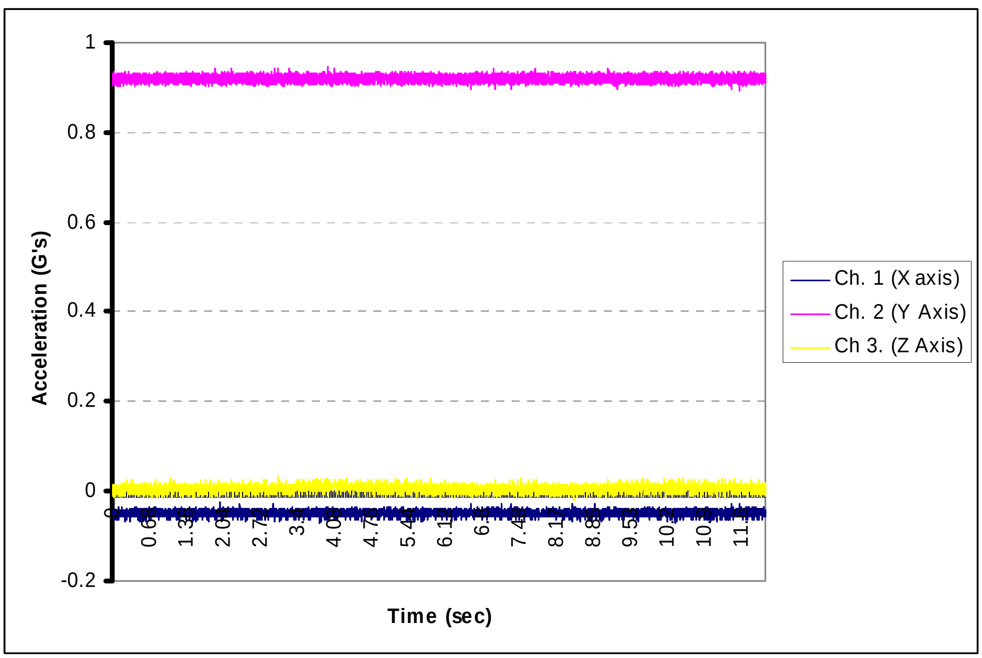

Figure 3.5 Baseline Reading of Accelerometer After Calibration.

The second calibration procedure was done to prove consistency in the accelerometer readings. A simple pendulum system was designed in which the accelerometer was attached an arm. The arm was raised to an 80° angle and released. This was performed three times and the data from accelerometer was recorded by the Agile-Link software, graphed and compared. The results are included in Figures 3.6.

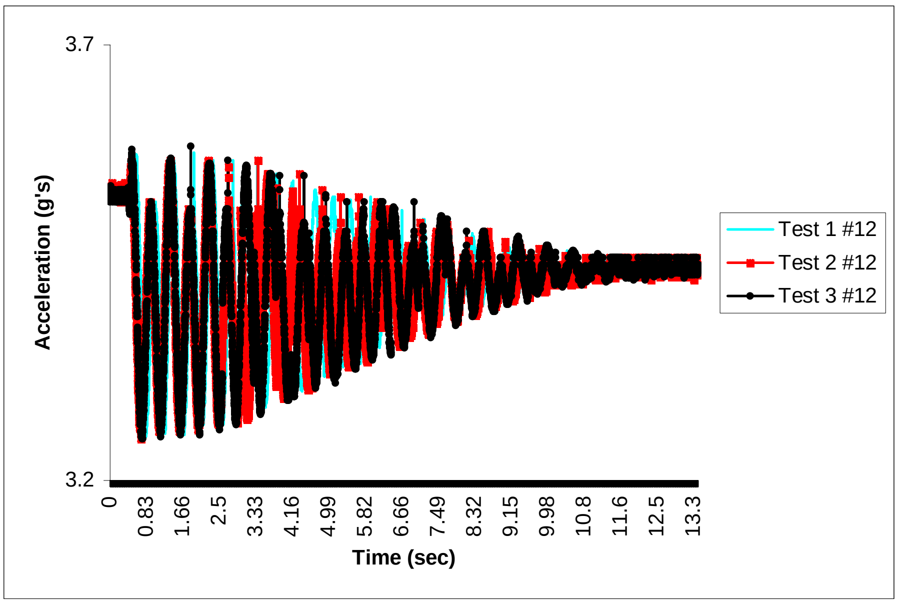

Figure 3.6 Pendulum Results for Accelerometer #12.

3.2.3 Study Protocol

The study was conducted in the Kopp Engineering Building at the University of South Florida. Participants were asked to fill out the appropriate survey depending on if they were an amputee or a control subject. The investigating staff recorded height, weight and leg lengths. After palpating the anterior superior iliac spine (ASIS), a tape measure was used to measure the distance from the ASIS to the medial malleolus to determine leg length (Keeling 2004). The footswitches were then attached using Johnson & Johnson First Aid Waterproof tape to the heel of the shoes that the participants were wearing and the wires were secured to the leg. An accelerometer enclosed in a plastic bag was then taped with the same tape as above to the back of the subjects at the L5-S1 level of the spine (Figure 3.7). This level was determined by locating the midpoint of a horizontal line that connected the right and left iliac crests [Van Herp, 2000]. Subjects were then asked to walk at three different speeds down the straight, hallway for 24 feet while the accelerometer was triggered to record the acceleration data and the footswitches recorded heel strikes. Also recorded were accelerations while the subject stood still for one minute. This allowed a baseline graph to be created which would show any abnormalities due to breathing and heart rate and to account for any deviations from the accelerometer not being aligned exactly with the axes of the room. The average of the baseline reading was used as the zero point for determining the maximum difference for all trials.

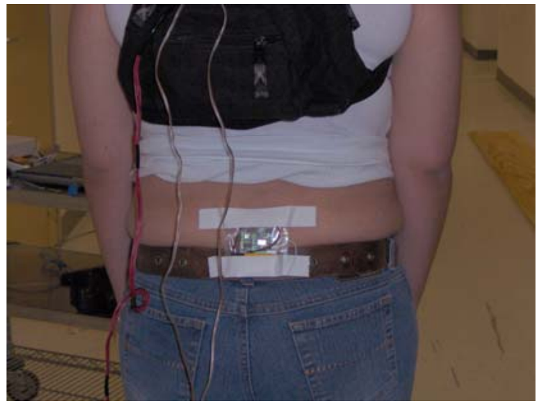

Figure 3.7 Accelerometer Attached to L5/S1 Level of Spine.

Eleven trials were conducted in all. Each of the selected paces for the walking trials was performed three times. For the first walking trial subjects walked at their own “normal” pace. For the second trial, subjects were informed to walk as fast as they could without running. This was considered the “fast” trial. The “slow” trial consisted of subjects walking as if they were browsing at a mall or window-shopping. After the three walking trials, subjects also walked with a simulated leg length difference. This was created by having the subject walk along a 16-foot by 1 foot piece of plywood with only one foot on the board (Figure 3.8). Using one or two ½ inch plywood created simulated leg length differences of ½ inch and 1 inch. For the amputee subjects, they performed four trials. Two consisted of simulating a prosthesis that was “too short” (prosthesis not on wood) and the other two a prosthesis that was “too long” (prosthesis on wood). Controls completed only two trials for this portion of the study, one ½ inch trial and one 1-inch trial. All control trials were performed with the right foot on the board.

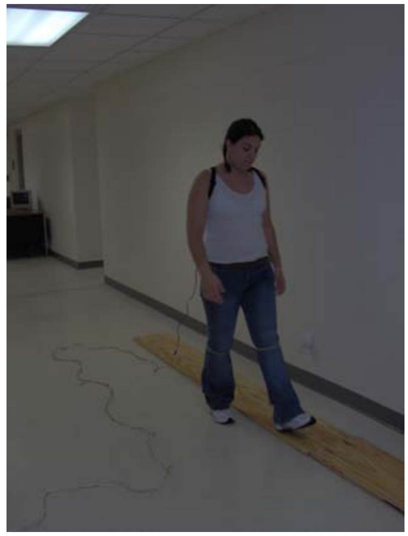

Figure 3.8 Simulated Leg Length Difference Set-up.

All subjects wore their usual walking shoes and were advised not to wear high heels or hard-soled shoes but tennis shoes before coming to the study. Subjects were asked not to talk and to swing their arms freely as they walked. Tape was used to mark the location of the beginning and ending point of the 24 foot distance. Also marked were a starting and ending point 2 feet before and after the 24 foot difference. Data was recorded only from the 24 foot length to exclude any beginning or ending differences in gait. Subjects were allowed several practice runs to get accustomed to wearing the accelerometer and footswitches and to walking at the indicated slow and fast paces.

Accelerometer #12 was used throughout the study. The accelerometer was placed inside the plastic bag with the y-axis aligned with the gravity vector (Figure 3.9). The subject was asked to begin walking and when he crossed the beginning of the 24-foot distance the accelerometer was triggered to collect data. The triggering of the accelerometer software also triggered the LabVIEW program to begin recording data from the footswitches. Also recorded was the starting foot for each subject and the time it took to walk the 24 feet or the 16 feet for the simulated leg length difference trials. From the walking time a speed was calculated for each trial by dividing the distance by the time. The Agile Link software automatically created an Excel spreadsheet file that consisted of the recorded accelerations from each axis and the sweep number. The accelerometers were configured so as to perform 10000 sweeps at a sweep rate of 829 sweeps/sec. The minimum acceleration value for each step was obtained from the graph of acceleration versus time. It was then subtracted from the average baseline reading to determine the maximum change (Figure 3.10). The values were tabulated according to trial type (normal, fast or slow) and trial number (1, 2, or 3) and separated into amputated versus non-amputated for amputees and left versus right for controls.

Figure 3.9 Accelerometer's y – axis Aligned with the Gravity Vector and Enclosed in a Plastic Bag.

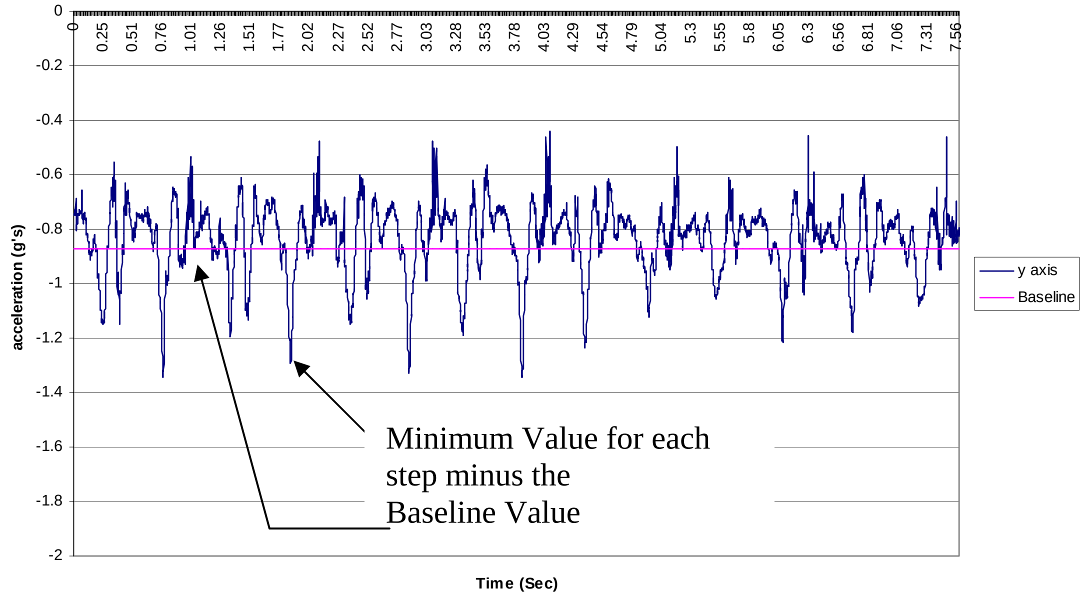

Figure 3.10 Determination of Maximum Difference from Agile-Link Output.

3.2.4 Data Analysis

Using the raw data obtained from the Agile-Link software, the minimum value for each step (as determined by the foot switches) was labeled and subtracted from the baseline reading to determine the maximum change in acceleration. A spreadsheet of all the maximum changes was created for each subject and trial. The mean and standard deviation of the maximum changes in acceleration for each subject and trial were also calculated.

Several other calculations were then made with these values. First, a delta value was created by subtracting the non-amputated value from the amputated value or the left from the right for the controls. The mean and standard deviations of the delta values were then calculated for each subject. The mean value should be zero, which shows a balance between both sides. The number of positive and negative values was then counted and a percent of negative values was calculated. The goal would be to have a percentage of 50% to show balance between the two sides. A percentage higher than 50% would show that when heel strike occurs for the amputated leg (or the right leg for controls) there is higher acceleration involved and the opposite for a percentage lower than 50%. Two proportion difference testing was used to determine if the percent negative values were significantly different from 50%. Table 3.3 shows a sample Excel Spreadsheet column for the delta values.

Secondly, a table of all the maximum changes was created and separated into non-amputated and amputated or left and right. For each trial type, the mean and standard deviation was calculated for each subject. After which the mean and standard deviation was calculated for amputees as a whole and controls as a whole. These averages were then plotted in a bar graph in Excel. A t-test and two proportion difference test was performed to determine if a significant difference was present between amputees and controls.

In addition to acceleration data obtained from the accelerometer itself, several subjects underwent gait analysis to validate the use of the accelerometer. A light-reflecting marker was placed over the accelerometer and an eight camera motion analysis system was used to record accelerations of the reflector, hence the spine at that location.

Table 3.3 Sample Delta Value Calculations.

	1A
	N
	0.5951
	-0.2195
	-0.2049
	-0.4342
	-0.5707
	-0.3561
	-0.7024
	-0.6537
	-0.6
	-0.5122
	-0.3854
	-0.6
	-0.2927
	-0.6292
	-0.2682
	-0.2927
	-0.7122
Mean	-0.40229
Std Dev	0.309437
Neg	16
Pos	1
%Neg	94.11765

The Motion Analysis system and EVART software were used to produce a data file containing the accelerations in the x, y, and z directions. The camera system and accelerometer were synchronized to record data at the same time. The results obtained were comparable.

4.0 Results

4.1 Survey Results

Appendix 5 and 6 contain the results from the two surveys distributed. The following table summarizes the demographics of the two populations.

Table 4.1 Summary of Survey Demographics.

		Controls	Amputees	Is Difference Significant ($p<0.05$)
Male		21	32	
Female		23	23	
Total		44	55	
Age (years)	Mean	35.86	50.64	Yes
	Standard Deviation	14.13	16.44	
Weight (lbs)	Mean	169.61	182.70	No
	Standard Deviation	41.46	56.58	
Height (in)	Mean	67.94	66.97	No
	Standard Deviation	4.08	7.28	
BMI	Mean	25.49	27.06	No
	Standard Deviation	3.92	10.03	

4.1.1 Amputees

52.73% of the sample was below the knee amputees, 41.82% were above the knee amputees, 3.64% were both and one subject was neither (this subject was excluded). There were 21 left-sided amputees, 25 right-sided amputees and 7 bilateral amputees surveyed (Two subjects did not respond to this question). The average time since amputation was 12.32 years. The majority of the amputees reported that they use their prosthesis 76-100% of the time while they are awake and the reasons for not using the prosthesis are summarized in Figure 4.1.

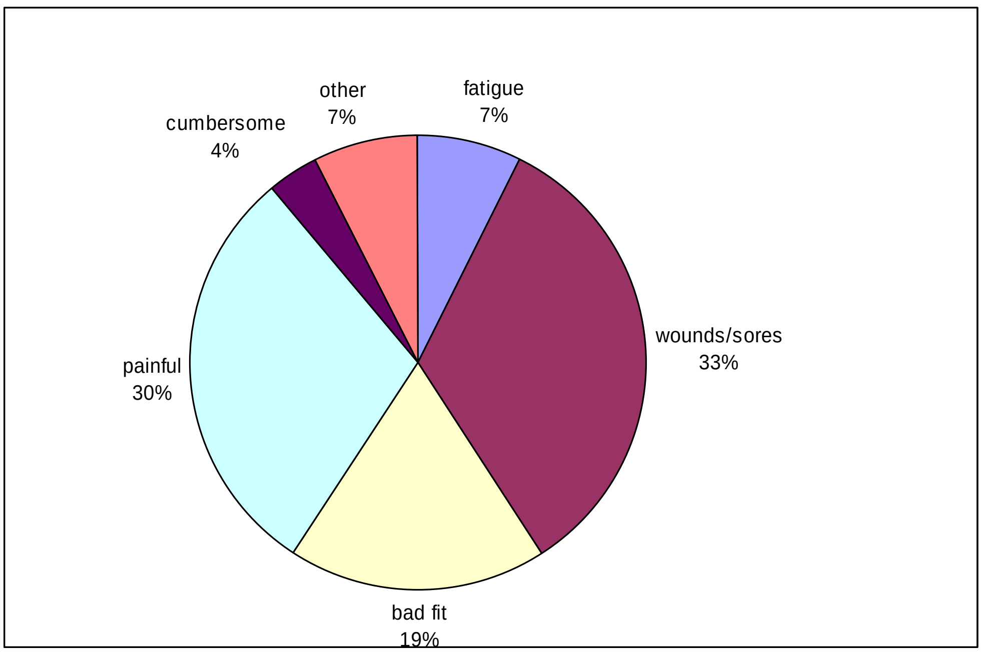

Figure 4.1 Reasons for Non-prosthesis use Among Amputees.

62.96% (n=34) of the amputees reported that they experience back pain. 75.93% of those with back pain reported that they do not have a medical condition that causes the pain, while the other 24.07% attribute the back pain to a certain medical condition. (Table 4.2)

Table 4.2 Medical Condition for Back Pain (Amputees).

Medical Condition	Number of Subjects
None	41
Fracture/Dislocation/ Deformation of Hip/Leg	4
Diabetes	1
Car Accident	3
Arthritis	1
Scoliosis/Spondylosis/Lordosis	2
Other	2

78.26% of those with back pain report that the pain is in their lower back and the majority (81.82%) is not seeing a specialist to alleviate the pain. Figures 4.2 – 4.4 are a breakdown of the nature, intensity and frequency of the pain experienced. For most amputees the pain only affected activities such as walking, sleeping, normal work, recreation, and the enjoyment of life a little bit (Appendix 5).

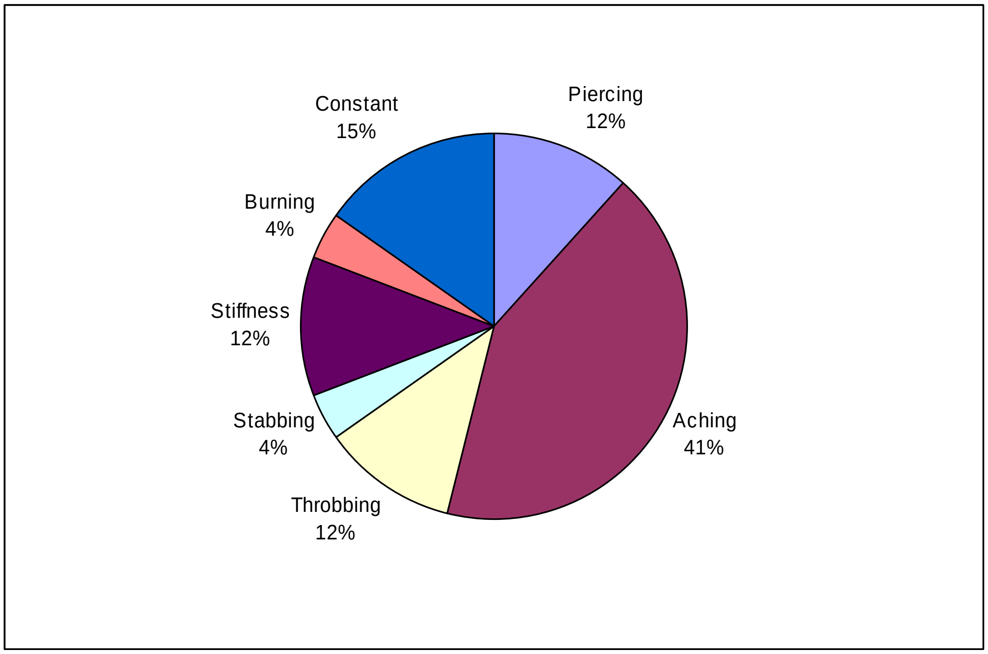

Figure 4.2 Nature of Amputee Back Pain.

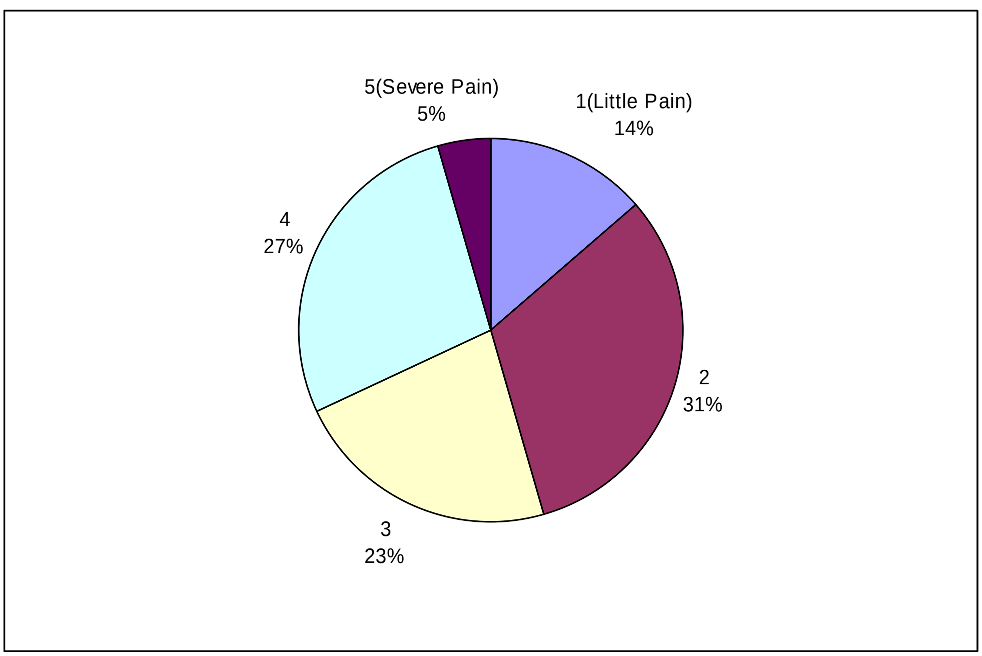

Figure 4.3 Intensity of Amputee Back Pain.

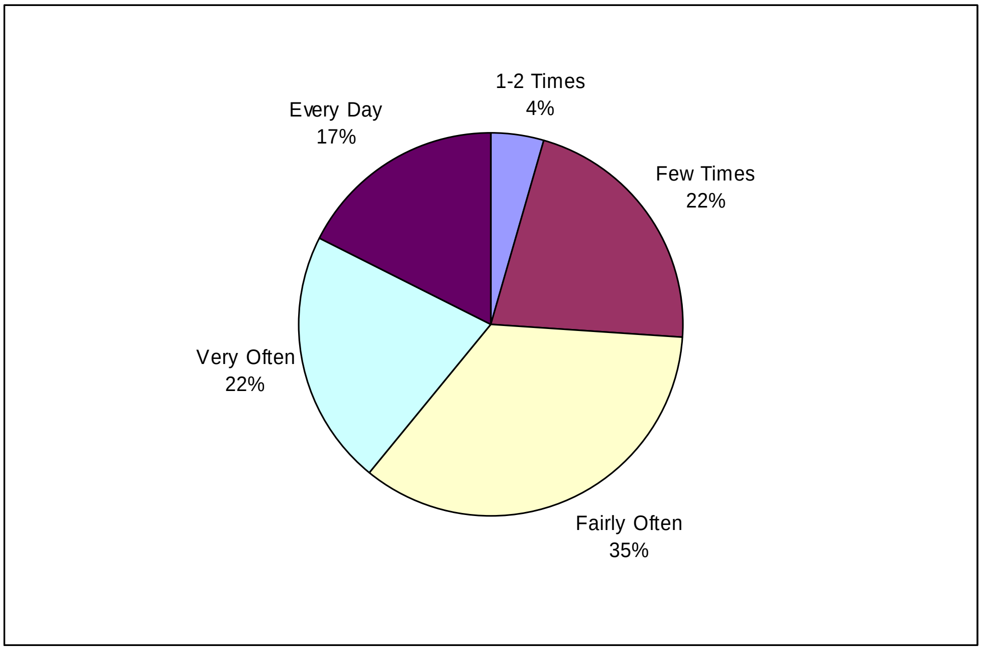

Figure 4.4 Frequency of Amputee Back Pain in the Last Four Weeks.

Just under half of the sample (48.08%) reported that they experience hip pain. This is in contrast to the 75.93% and 77.78% that experience phantom pain and phantom sensation respectively. Half of the amputees who suffer from phantom pain or phantom sensation rate it as severe (4 or 5). Figures 4.5 and 4.6 represent the number of people suffering from phantom pain or sensation and how they rate the intensity level.

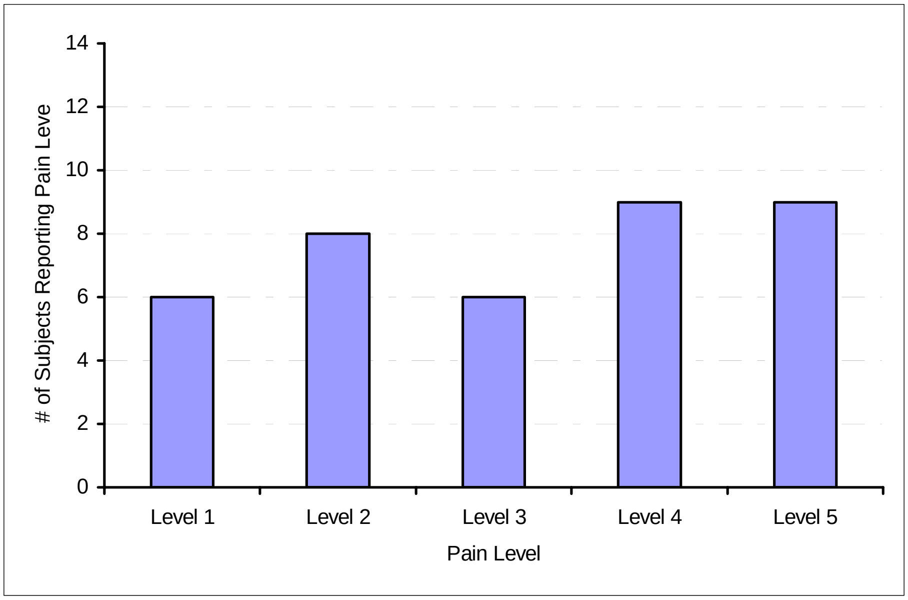

Figure 4.5 Level of Phantom Pain Among Amputees.

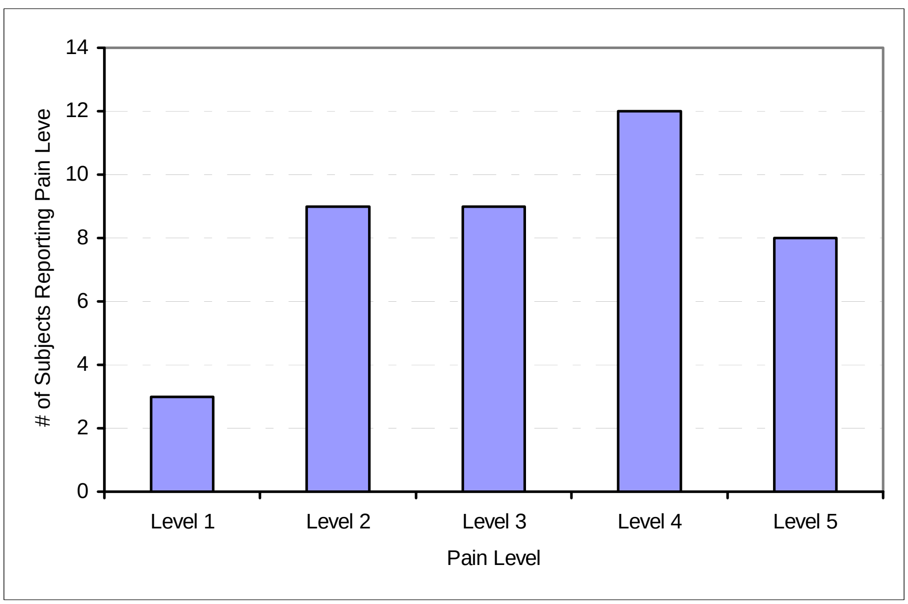

Figure 4.6 Level of Phantom Sensation Among Amputees.

4.1.2 Controls

The sample was evenly split with 22 reporting back pain and 22 reporting they do not experience back pain. Of the 22 that reported back pain, 22.73% attributed it to a medical condition (Table 4.3) while 77.27% reported that there was no specific condition that caused the pain.

Table 4.3 Medical Condition for Back Pain (Controls).

Medical Condition	Number of Subjects
None	34
Fracture/Dislocation/ Deformation of Hip/Leg	0
Diabetes	0
Car Accident	2
Arthritis	2
Scoliosis/Spondylosis/Lordosis	4
Other	2

92.31% of those with back pain report that the pain is located in their lower back. Nearly all of those with pain (90.48%) are not seeing a specialist for it. Figures 4.7- 4.9 show the percentages for the nature, intensity and frequency of pain. A rating of 1 (not at all) was the most frequent response to the pain’s effect on walking, sleeping, normal work, recreation, and enjoyment of life (Appendix 6).

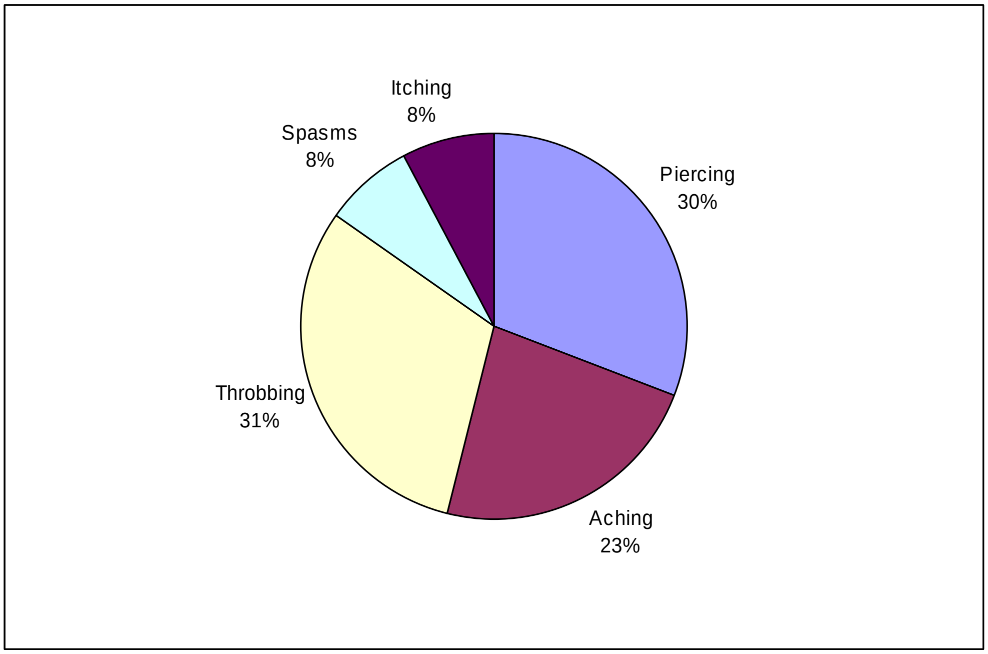

Figure 4.7 Nature of Back Pain – Controls.

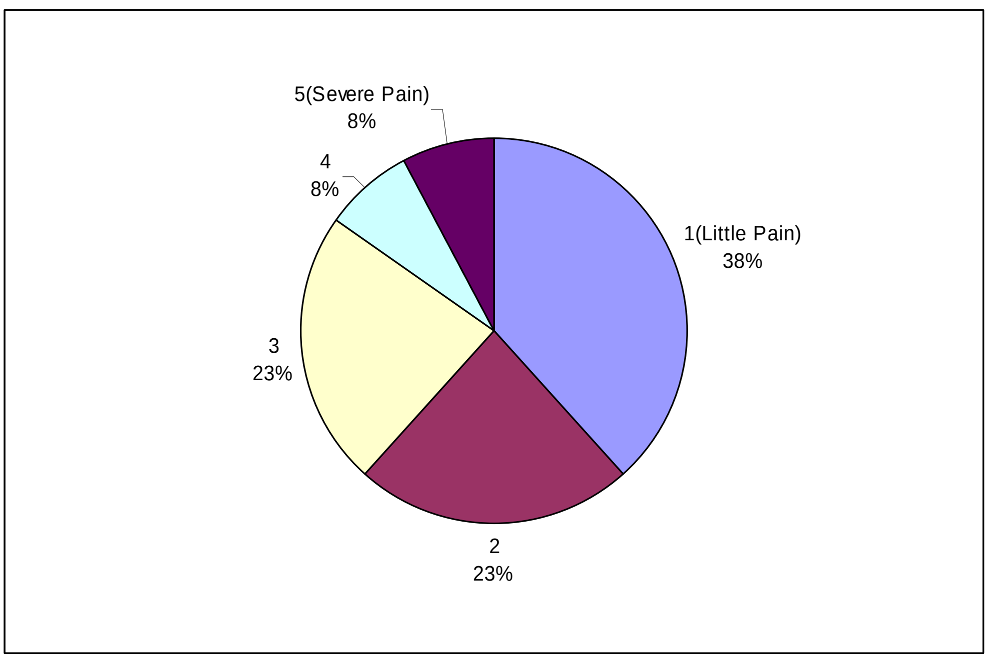

Figure 4.8 Intensity of Back Pain – Controls.

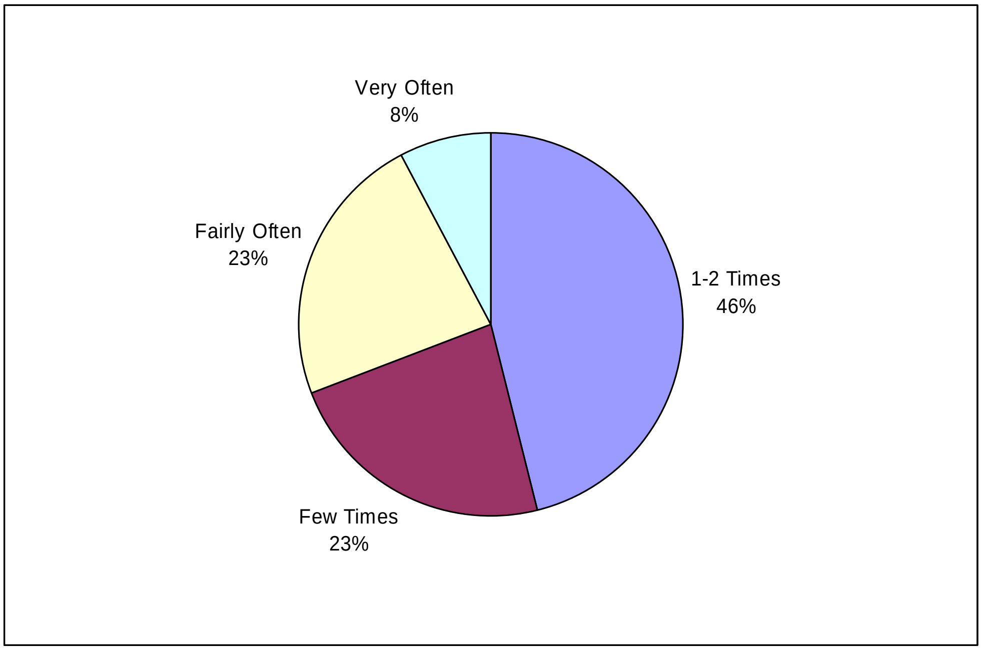

Figure 4.9 Frequency of Back Pain in the Last Four Weeks – Controls.

4.1.3 Comparison of Amputees and Controls

The following table is a comparison of the back pain results for amputees versus controls.

Table 4.4 Comparison of Survey Results on Back Pain for Amputees versus Controls.

	Amputees	Controls	Is Difference Significant (p<0.05)
Experience Back Pain	62.96%	50.00%	No
Pain Located in the Low Back	78.26%	92.31%	Yes
Nature of the Pain	Aching (41.00%)	Throbbing/Piercing (30.00%)	
Intensity of the Pain	2 (31%)	1 (38%)	
Frequency of the Pain	Fairly Often (35%)	1-2 Times (46%)	
Hip Pain	48.08%	19.05%	Yes

4.2 Accelerometer Results

The results of the surveys given to the subjects of the accelerometer study can be found in Appendix 7 and 8. Table 4.5 summaries the demographics of those recruited.

Table 4.5 Summary of Subject Demographics.

		Controls	Amputees	Is Difference Significant (p<0.05)
Male		2	2	
Female		1	1	
Total		3	3	
Age (years)	Mean	29.00	42.67	No
	Standard Deviation	7.94	13.61	
Weight (lbs)	Mean	173.83	169.33	No
	Standard Deviation	13.81	40.46	
Height (in)	Mean	67.83	67.42	No
	Standard Deviation	2.25	2.67	
BMI	Mean	26.56	25.95	No
	Standard Deviation	1.72	4.00	

4.2.1 Amputees

Four amputees, three male and one female, were recruited to participate in the accelerometer study. One of the males was excluded from the results due to the inability to complete the trials.

All three subjects were below the knee amputees with two having the right side amputated and one the left side. All three reported being able to stand still for 46 minutes or more and that the only reason for disuse of the prosthesis was sleeping or showering. Two out of three reported having back pain. The pain intensity was rated as little pain occurring in the lower back once or twice in the last four weeks.

One out of three amputees reported having hip pain. One out three reported having phantom pain. Two out of three reported having phantom sensation and one out of three reported pain in the leg that was not amputated.

Subject 1A has been an amputee for 20 years and subject 3A has been an amputee for 56 years. Subject 2A has had the most recent amputation occurring only 1 year ago.

All three subjects were able to walk independently and complete all trials. Table 4.6 summarizes the data collected in the subject information sheet.

Table 4.6 Summary of Information from the Subject Information Sheet (Amputees).

Subject #	Age	Height (in)	Weight (lbs)	BMI	Average Speed(ft/sec) for Normal Trials	Average Speed(ft/sec) for Fast Trials	Average Speed(ft/sec) for Slow Trials	LLD (in)
1	38	66.0	144	23.24	3.35	4.11	1.88	0.0
2	32	70.5	216	30.55	4.27	5.72	3.48	0.5
3	58	65.8	148	24.07	4.14	5.75	3.15	0.3

4.2.2 Controls

One out of three subjects reported that they experience back pain compared to the two amputee subjects that reported pain. The pain is attributed to an injury that occurred and is located in the lower back. It was reported that the pain has not occurred in the last four weeks but that when it does occur it is severe and can moderately to extremely affect the activities of daily living.

Table 4.7 summarizes the data obtained from the subject information sheet for the walking trials. All three subjects were able to complete all trials.

Table 4.7 Summary of Information from the Subject Information Sheet (Controls).

Subject #	Age	Height (in)	Weight (lbs)	BMI	Average Speed(ft/sec) for Normal Trials	Average Speed(ft/sec) for Fast Trials	Average Speed(ft/sec) for Slow Trials	LLD (in)
1C	20	65.5	170.5	27.94	3.66	5.93	2.54	0.0
2C	32	68.0	162	24.63	4.16	6.75	4.09	0.0
3C	35	70.0	189	27.11	4.56	7.39	2.93	0.5

4.2.3 Accelerations

Table 4.8 is a summary of the baseline readings from the y-axis while standing still for each subject. There is no significant difference between these values ($p < 0.05$).

Table 4.8 Baseline Accelerations.

Subject #	Baseline Acceleration (y component only)(g's)
1A	-0.89
2A	-0.83
3A	-0.89
1C	-0.87
2C	-0.88
3C	-0.89

The minimum value for each step was labeled and this was the value used to determine the maximum change in acceleration (peak acceleration) along with the baseline reading. Appendix 9 contains the Excel spreadsheet of the maximum changes for all subjects and trials. The mean and standard deviation of the maximum changes in acceleration for each subject and trial were calculated. The results are included in Appendix 10. Also calculated was the mean and standard deviation of the two different populations (amputees and controls).

4.2.3.1 Walking Trials

The data obtained is from a small population of subjects (n=6) but there is evidence that a difference is present between the amputee and control groups. As determined using the foot switches, the maximum change in acceleration occurred just before heel strike. The average maximum change in acceleration for the amputated leg was consistently higher than values for the non-amputated leg and both the left and right leg of the control subjects throughout all trials (Figures 4.10- 4.15)

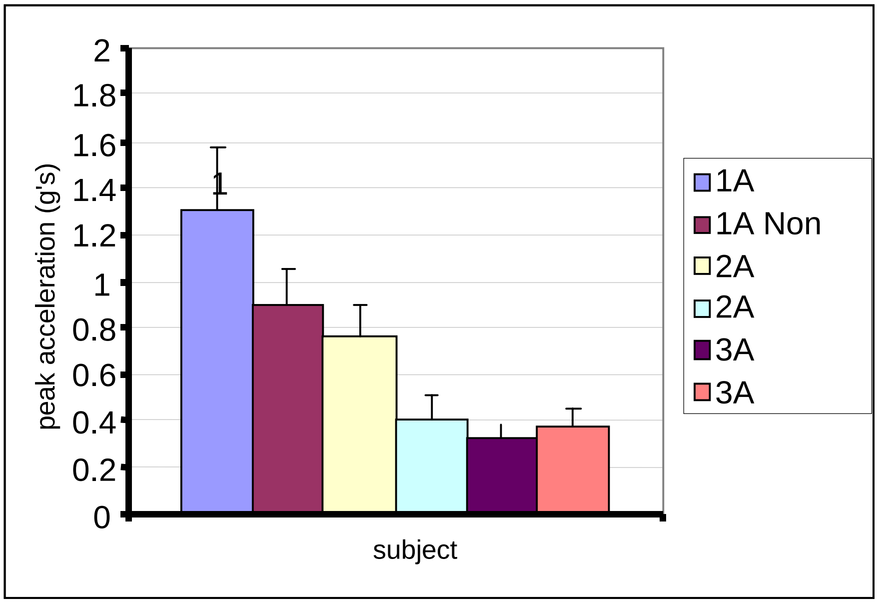

Figure 4.10 Peak Acceleration for the Normal Walking Speed Trials of Amputees: Amputated vs Non-amputated. Mean and Standard Deviation Error Bars are Shown.

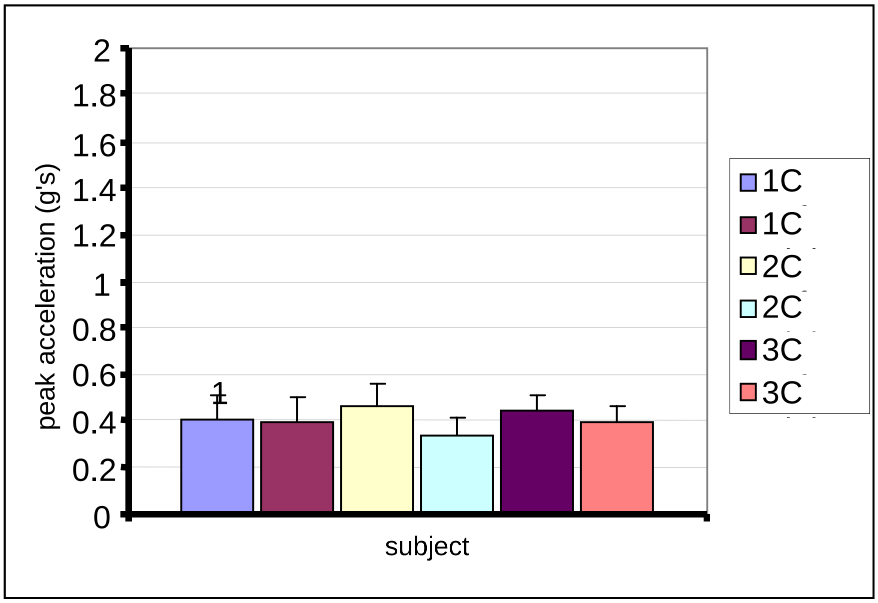

Figure 4.11 Peak Acceleration for the Normal Walking Speed Trials of Controls: Left vs Right. Means and Standard Deviation Error Bars are Shown.

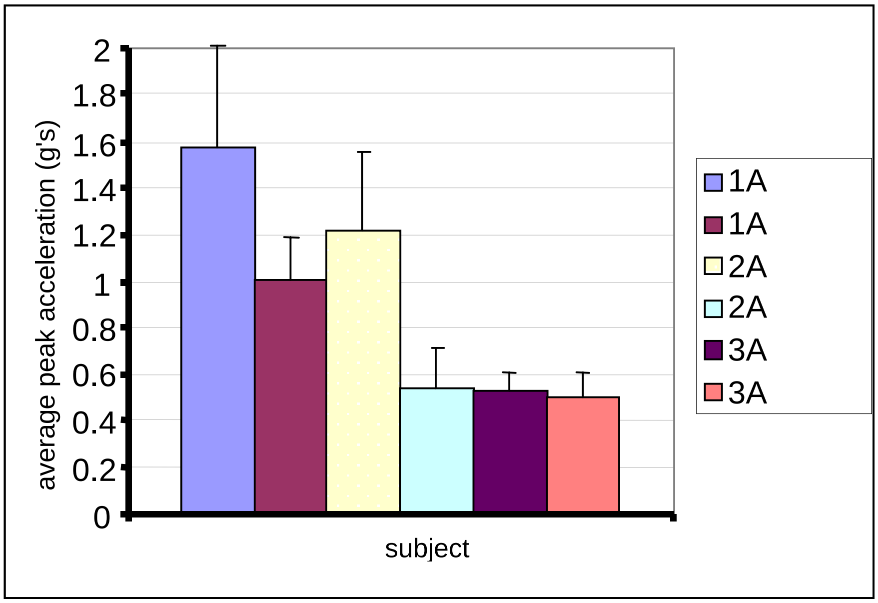

Figure 4.12 Peak Acceleration for the Fast Walking Speed Trials of Amputees: Amputated vs Non-amputated. Means and Standard Deviation Error Bars are Shown.

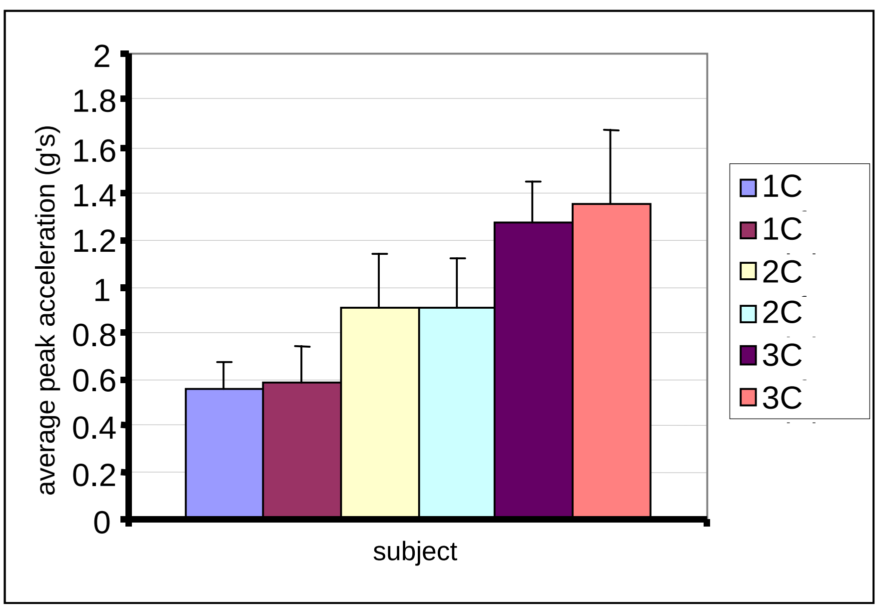

Figure 4.13 Peak Acceleration for the Fast Walking Speed Trials of Controls: Left vs Right. Means and Standard Deviation Error Bars are Shown.

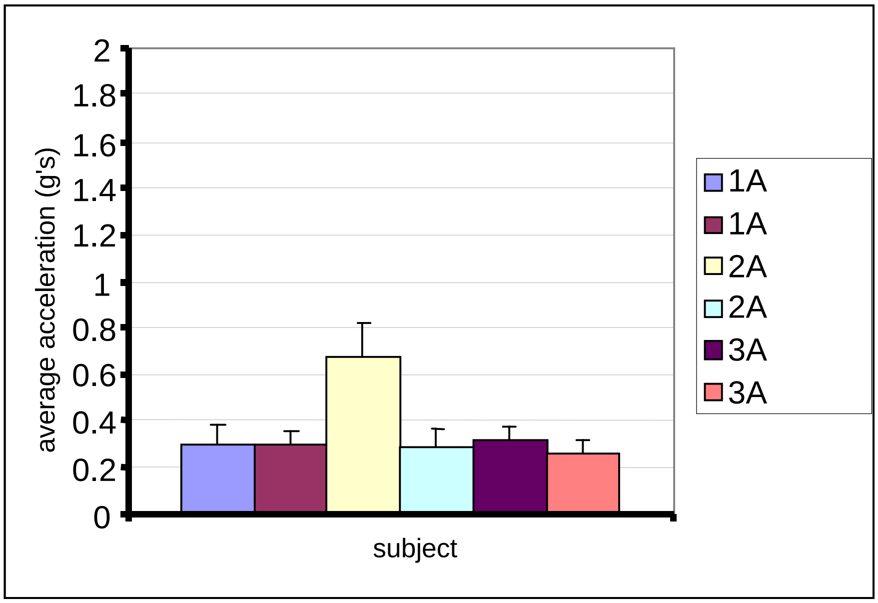

Figure 4.14 Peak Acceleration for the Slow Walking Speed Trials of Amputees: Amputated vs Non-amputated. Means and Standard Deviation Error Bars are Shown.

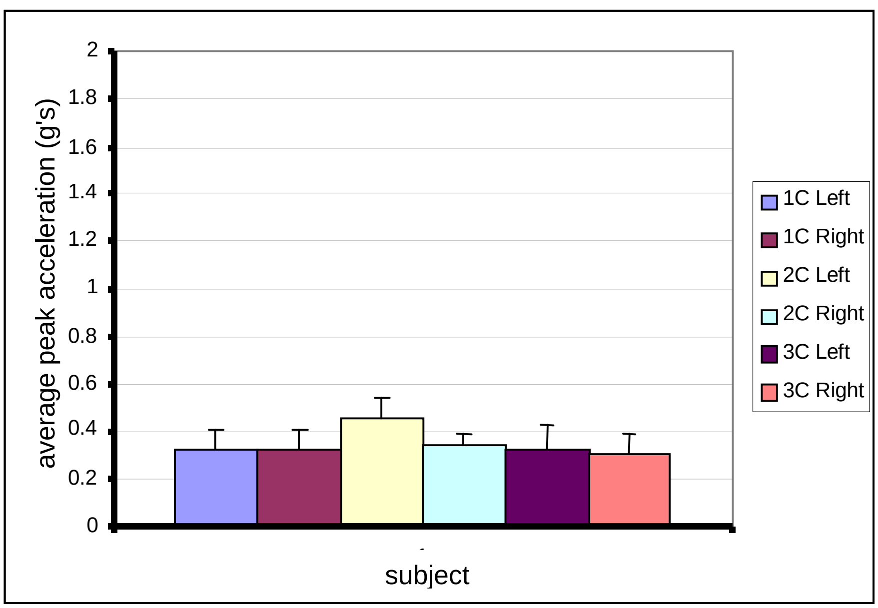

Figure 4.15 Peak Acceleration for the Slow Walking Speed Trials of Controls: Left vs Right. Means and Standard Deviation Error Bars are Shown.

The highest peak acceleration occurred during the fast trial of subject 1A and was 2.32 g's. This subject recorded the highest average peak accelerations for the fast and normal trials while subject 2A recorded the highest average peak acceleration for the slow trials. Table 4.9 contains the average peak acceleration values for amputees as a whole and controls as a whole for all walking trials. The average peak acceleration values for amputees are higher than the controls across all trials (Figures 4.16- 4.18). Figure 4.19 compares the average peak acceleration values for amputees versus controls for different walking speeds. Only the normal walking trials show a significant difference ($p<0.05$) between the two populations.

Table 4.9 Average Peak Acceleration for Populations as a Whole.

		Slow Trials	Normal Trials	Fast Trials
Amputees	Mean (g's)	0.35	0.69	0.92
	Standard Deviation	0.16	0.39	0.48
Controls	Mean (g's)	0.34	0.41	0.89
	Standard Deviation	0.10	0.09	0.38
p – value for significance		0.883	0.065	0.891

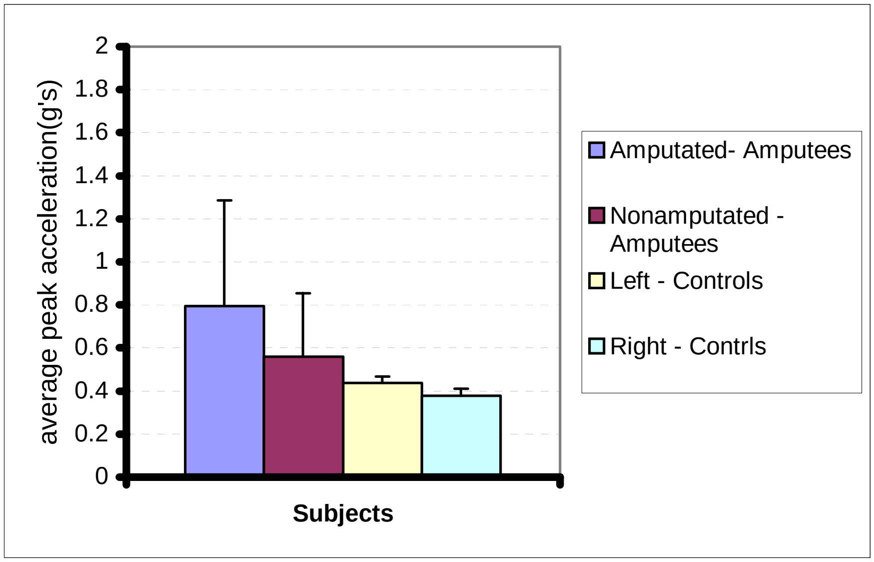

Figure 4.16 Average Peak Acceleration for the Normal Walking Speed Trials: Amputees vs Controls. Means and Standard Deviation Error Bars are Shown.

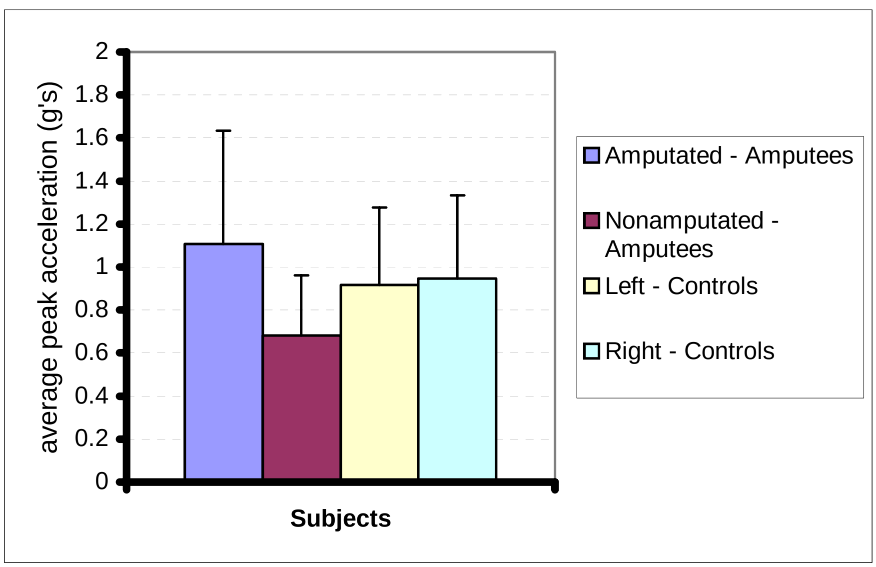

Figure 4.17 Average Peak Acceleration for the Fast Walking Speed Trials: Amputees vs Controls. Means and Standard Deviation Error Bars are Shown.

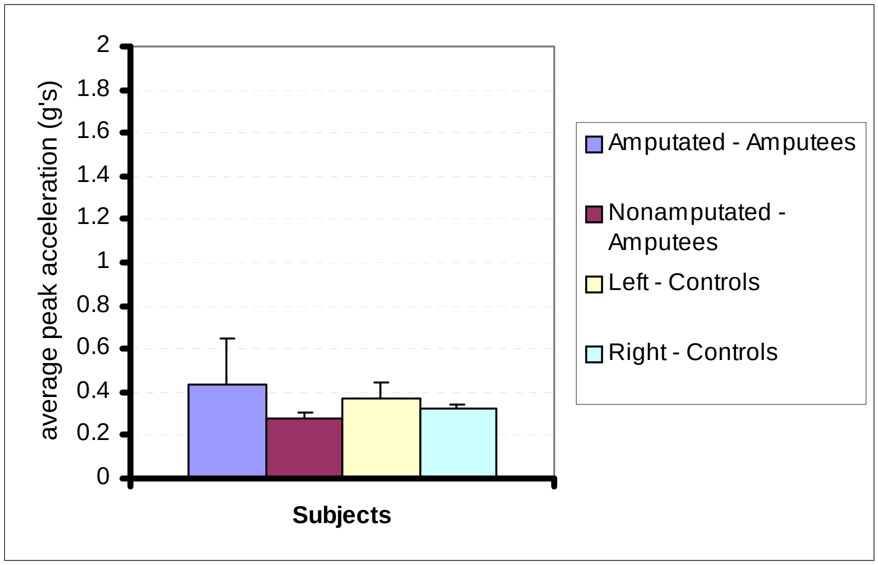

Figure 4.18 Average Peak Acceleration for the Slow Walking Speed Trials: Amputees vs Controls. Means and Standard Deviation Error Bars are Shown.

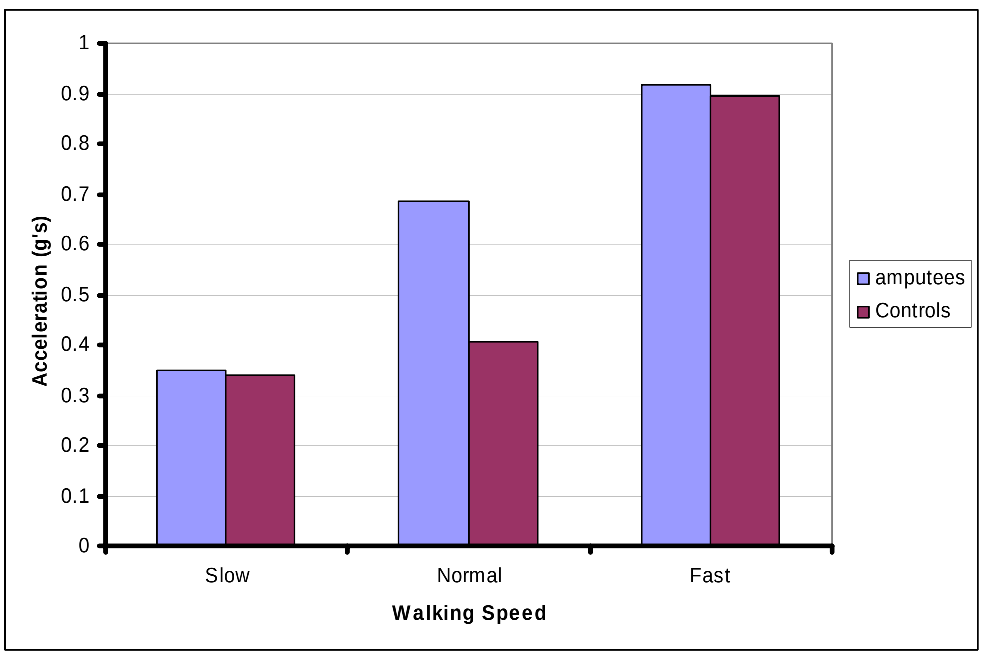

Figure 4.19 Total Acceleration for Different Walking Speeds.

Also of importance is the difference between the maximum peak acceleration values for opposing legs (Table 4.10). All of the walking trials for amputees showed a significant difference between opposing legs. For controls only the normal walking trial showed a difference between the left and right side. In the amputee population the average difference between amputated and non-amputated leg is as large as 0.42 g's, which occurred during the fast trials. For the control population the average difference only reached a maximum of 0.06 g's, which occurred during the normal trials. Table 4.11 shows the differences between opposing legs for all subjects. Subject 2A had the largest difference between opposing legs and subject 1A had the smallest difference.

The largest difference (0.39 g's) between amputee and control subjects was seen in the fast trials. The slow trials had the smallest difference (0.12 g's). Figure 4.20 compares the average difference between opposing legs for amputees versus controls for different walking speeds. The difference between amputees and controls is significant ($p<0.05$) across all walking speeds.

Table 4.10 Average Differences between Opposing Legs.

Trial	Normal	Fast	Slow
Amputated Average Peak Acceleration (g's) and Standard Deviation	0.80 +/- 0.49	1.11 +/- 0.53	0.43 +/- 0.21
Non-Amputated Average Peak Acceleration (g's) and Standard Deviation	0.56 +/- 0.29	0.68 +/- 0.28	0.28 +/- 0.02
Difference between Amputated and Non-Amputated Values	0.24	0.42	0.15
Is difference significant	Yes	Yes	Yes
Left Average Peak Acceleration (g's) and Standard Deviation	0.44 +/- 0.03	0.92 +/- 0.36	0.37 +/- 0.07
Right Average Peak Acceleration (g's) and Standard Deviation	0.38 +/- 0.03	0.95 +/- 0.39	0.33 +/- 0.02
Difference between Left and Right Values	0.06	0.03	0.04
Is difference significant?	Yes	No	No

Table 4.11 Differences (g's) between Average Peak Acceleration of Opposing Legs Across Many Steps for Each Subject.

Subject	Normal	Fast	Slow
1A	0.40	0.56	0.00
2A	0.36	0.68	0.39
3A	0.06	0.00	0.06
1C	0.01	0.03	0.00
2C	0.13	0.00	0.09
3C	0.05	0.07	0.03

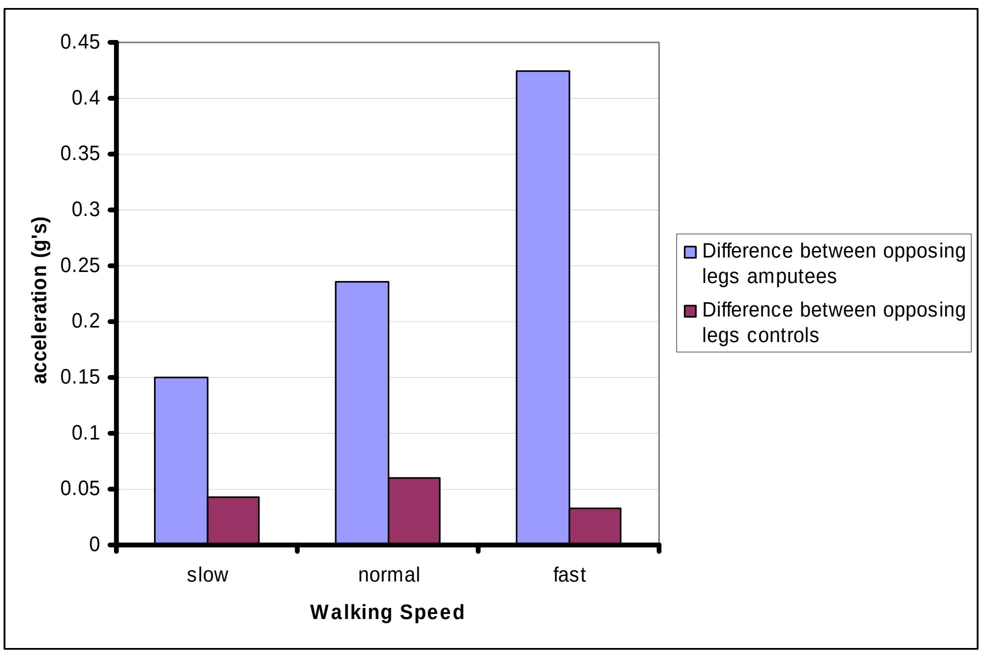

Figure 4.20 Differences between Opposing Legs for Different Walking Speeds.

The delta value results obtained by subtracting the amputated from the non-amputated values for amputees or the right from the left values for controls are included in Appendix 11. Table 4.12 contains the results from the delta value calculations. A single proportion statistical analysis of each subject's percent negative values showed that with 95% confidence all amputees demonstrated a side preference in all walking trials.

Table 4.12 Delta Value Analysis.

Trial	Subject	Mean	Standard Deviation	# of Negative Values	# of Positive Values	% of Negative Values	Is the % value different from 50%
Normal	1A	-0.40	0.31	16	1	94.1	Yes
	2A	-0.36	0.11	15	0	100.0	Yes
	3A	0.07	0.11	5	12	29.4	Yes
	1C	0.01	0.14	8	11	42.1	No
	2C	0.13	0.14	3	11	21.4	Yes
	3C	0.01	0.14	5	9	35.7	No
Fast	1A	-0.56	0.50	16	1	94.1	Yes
	2A	-0.71	0.41	13	0	100.0	Yes
	3A	0.00	0.20	8	7	53.3	No
	1C	0.01	0.20	10	6	62.5	No
	2C	0.09	0.29	3	8	27.3	Yes
	3C	-0.37	0.78	7	6	53.8	No
Slow	1A	-0.01	0.14	12	11	52.2	No
	2A	-0.37	0.28	15	2	88.2	Yes
	3A	-0.06	0.11	13	5	72.2	Yes
	1C	0.01	0.15	12	8	60.0	No
	2C	0.10	0.18	2	12	14.3	Yes
	3C	0.03	0.15	7	13	35.0	No

4.2.3.2 Simulated Leg Length Difference (LLD) Trials

The average peak acceleration for the amputees was again higher than that for the controls (Figures 4.21 - 4.24). But the amputated leg average was only higher than the non-amputated leg average during the trials in which the prosthesis was too long (Figures 4.21 - 4.22). For trials that created a prosthesis that was too short, the non-amputated averages were higher (Figures 4.23 – 4.24).

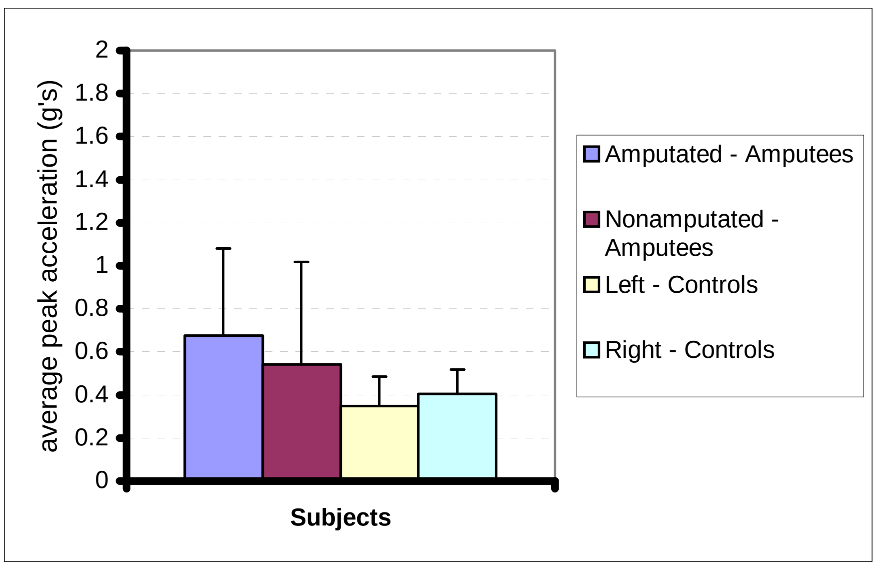

Figure 4.21 Average Peak Acceleration for the ½ in. Long Trials: Amputees vs Controls. Means and Standard Deviation Error Bars are Shown.

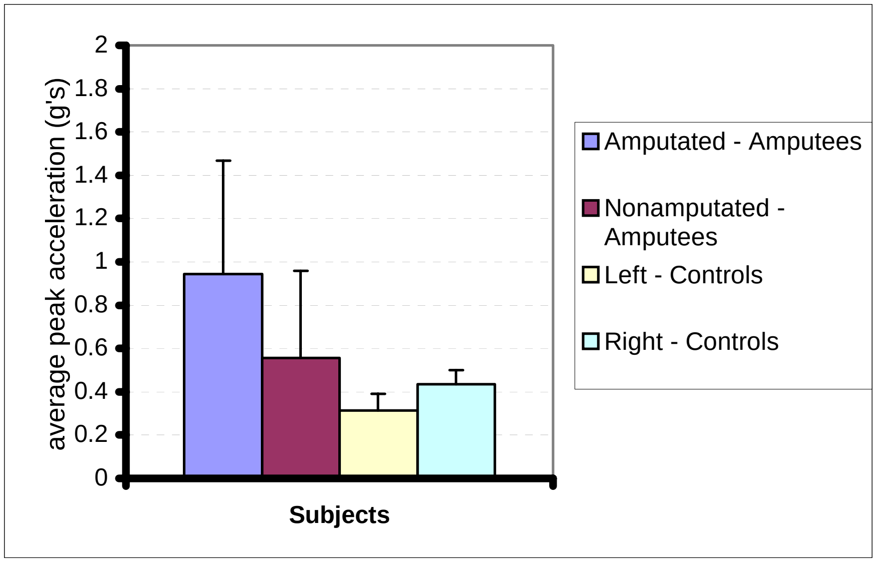

Figure 4.22 Average Peak Acceleration of the 1 in. Long Trials: Amputees vs Controls. Means and Standard Deviation Error Bars are Shown.

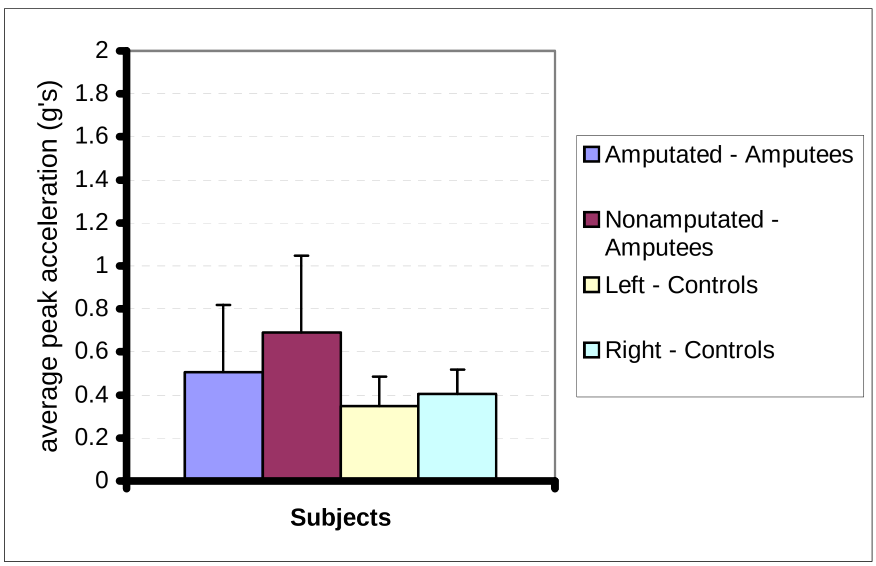

Figure 4.23 Average Peak Acceleration of the ½ in. Short Trials: Amputees vs Controls. Means and Standard Deviation Error Bars are Shown.

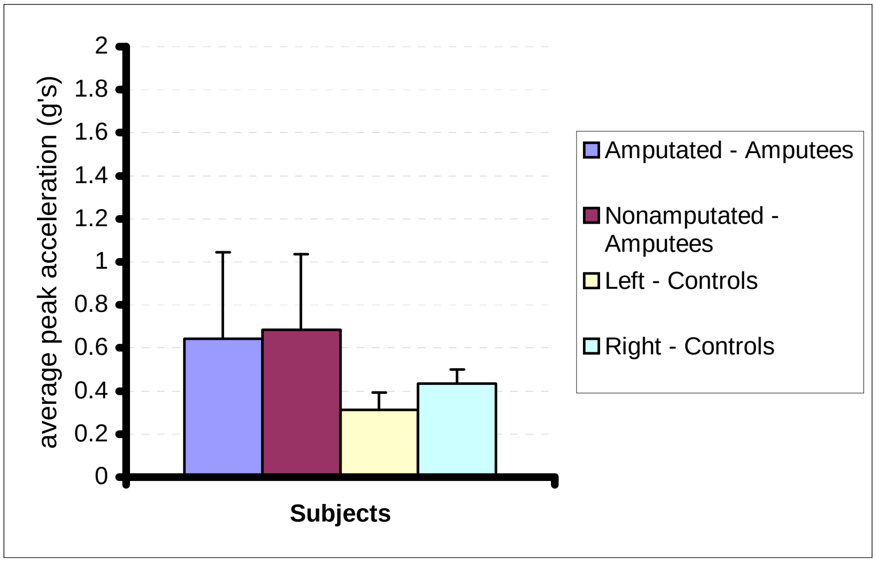

Figure 4.24 Average Peak Acceleration of the 1 in. Short Trials: Amputees vs Controls. Means and Standard Deviation Error Bars are Shown.

The highest peak acceleration value (1.91 g's) occurred during the 1 inch long trial of subject 2A. Table 4.13 contains the average peak acceleration of the amputees as a group and the controls as a group for the LLD trials.

Table 4.13 Average Peak Acceleration for Populations as a Whole (LLD Trials).

		½ in. Long	1 in. Long	½ in. Short	1 in. Short
Amputees	Mean (g's)	0.61	0.72	0.58	0.68
	Standard Deviation	0.42	0.48	0.34	0.38
Controls	Mean (g's)	0.38	0.36		
	Standard Deviation	0.15	0.14		

During the LLD trials the differences between opposing legs were not as predictable. Table 4.14 contains the average differences for amputees versus controls. (Note: The controls only completed 2 trials for this part of the study. There is no difference between the short and long trials for controls. The results for subject 2A's 1 inch short trial were not available). The largest difference is seen in the 1 inch long trials of the amputees, 0.39 g's.

The delta values for the LLD trials are included in Appendix 11. The results obtained from these values are included in Table 4.15.

Table 4.14 Average Differences in Average Peak Acceleration for LLD Trials.

Trial	Amputated Average Peak Acceleration (g's)	Non-Amputated Average Peak Acceleration (g's)	Difference between Peak Averages (g's)	Left Average Peak Acceleration (g's)	Right Average Peak Acceleration (g's)	Difference between Peak Averages (g's)
½ in Short	0.50	0.69	0.19	0.35	0.40	0.05
1 in Short	0.64	0.68	0.04	0.31	0.43	0.12
½ in Long	0.68	0.54	0.14	0.35	0.40	0.05
1 in Long	0.94	0.56	0.39	0.31	0.43	0.12

Table 4.15 Delta Value Calculations for the LLD Trials.

Trial	Subject	Mean	Standard Deviation	# of Negative Values	# of Positive Values	% of Negative Values
½ in Long	1A	0.08	0.55	2	2	50.0
	2A	-0.60	0.22	4	0	100.0
	3A	0.00	0.12	2	3	40.0
	1C	-0.15	0.08	4	0	100.0
	2C	-0.28	0.17	4	0	100.0
	3C	0.18	0.10	0	5	0.0
1 in Long	1A	-0.12	0.19	2	1	66.7
	2A	-1.15	0.35	4	0	100.0
	3A	-0.05	0.24	2	3	40.0
	1C	-0.16	0.19	4	1	80.0
	2C	-0.09	0.25	2	1	66.7
	3C	0.04	0.24	2	4	33.3
½ in Short	1A	-0.07	0.73	1	3	25.0
	2A	0.33	0.43	1	2	33.3
	3A	0.03	0.09	2	2	50.0
1 in Short	1A	0.01	0.65	2	2	50.0
	3A	-0.04	0.33	1	3	25.0

5.0 Discussion

5.1 Survey

The findings of this study are consistent with those who found that back pain was a significant complaint among lower limb amputees. The 62.96% of this study's population that complained of back pain is comparable to previous studies [Ehde, et. al (50%); University of Sterling (75%); Smith et. al (50%)]. However, this study found the prevalence of back pain among amputees to be higher than that of the general population. Nachemson [1971] found that 88% of the general population experiences back pain. This is in contrast to the 50% found in this study. Reasons for this discrepancy could be due to the unknown make-up of the population used in Nachemson's study. The control group used in this study consisted only of non-amputees and amputees may have been included in his population.

Nearly half of the amputee population reported that the back pain intensity was in the mild range and that it only slightly interfered with daily activities. This contrasts with Ehde's study that reported the pain significantly interfered with daily activities. In agreement with Ehde, this study found no significant differences between the percentage of below the knee (64.29%) and above the knee (69.57%) amputees that experience back pain. The rating of the intensity of the pain was only slightly higher for below the knee amputees compared to above the knee amputees. This is in contrast to Smith et al. who found that above the knee amputees reported a greater intensity of back pain.

The study has shown that most people who suffer from back pain experience the pain in the lower back and that there is no specific medical reason for the pain. It occurs more often among the amputee population than that of the controls and with greater intensity. In contrast to the amputees the controls report that the pain does not interfere at all with daily activities.

Based on Pearson correlation coefficients, there was only one correlation of significance ($p<0.05$) for the control population. It was found that body mass index correlated negatively with gender ($p=0.0002$). Men, on average, had a higher BMI than women. Among amputees the same result was found although without as strong a correlation ($p=0.0057$). For amputees the strongest correlation was between age and if the subject takes medication ($p=0.0001$) which would be expected. Several variables showed trends that with a higher sample size may prove to be significant correlations. Back pain negatively correlated with gender showing a trend that more men suffer from back pain. Results show a trend that when a subject experiences back pain he or she also experiences hip pain ($p=0.0732$).

5.2 Accelerometer Study

With only a small number of subjects, a major finding of this study is that the accelerometer can be a useful tool in studying the biomechanical aspects of amputee gait and imbalances that may be present. The differences shown between the amputees and controls are significant enough to warrant further investigation. Although it is unclear from this study whether or not these differences are a key factor in back pain, they may be useful in determining proper fit and therapy for amputees.

The maximum acceleration values correlated with which leg was amputated. The values for the amputated side were consistently higher than that of the non-amputated side. The increased acceleration values show that the prosthesis causes some change in muscle and ligament function. This is evident in the fact that the control population does not have as significant a difference between opposing legs. The difference could be attributed to the fact that the muscles and ligaments need to work more to stabilize the residual limb in the prosthesis and to stabilize the body over the prosthesis. With a better fit and therapy for the residual limb these differences may disappear.

Several trends have emerged from the results of this study. A comparison of the results from the delta value calculations show that there is a trend that more amputees demonstrate a side preference (% negative values are different from 50%) when compared to controls. All amputees demonstrated a side preference in all walking trials. This is compared to only one out of three controls (Table 4.12). Two out of three amputees have greater acceleration values when the amputated leg strikes the ground (%negative values >50%). The third amputee had a higher acceleration when the non-amputated foot struck the ground. This amputee has had the longest time since amputation, which may play a factor in the difference. The type of prosthesis did not play a role in limiting the acceleration. Subject 2A had the most sophisticated prosthesis but his acceleration values were not the lowest.

Another trend observable from this data is that speed influences the difference between opposing legs for amputees but not so much for controls (Figure 4.19). The difference between the non-amputated and amputated leg of amputees increases as the walking speed increases. There is no correlation for the control subjects. This shows that the differences caused by the prosthesis are amplified when the speed increases.

From Figure 4.20 one can see that as speed increases acceleration of the spine also increases. The only significant difference in the magnitudes of the average peak acceleration values is seen in the normal trials. This shows that on an everyday basis amputees experience higher acceleration than do non-amputees. As you deviate from normal walking speeds, the non-amputees experience the same magnitude of acceleration. This trend may be attributable to the accommodation of gait patterns for speeds outside of the normal. In general the amputees walked at a lower average speed for each trial when compared to controls (Table 5.1). With the experimental set-up allowing subjects to walk at speeds in which they deemed appropriate the trend is that amputees perceive speeds as slower than non-amputees. The acceleration values for amputees would actually be higher than controls walking at the same speed.

Table 5.1 Average Walking Speed per Trial.

	Slow (ft/s) Standard Deviation included	Normal (ft/s) Standard Deviation Included	Fast (ft/s) Standard Deviation Included
Amputees	2.84 +/- 0.85	3.92 +/- 0.49	5.20 +/- 0.94
Controls	3.19 +/- 0.80	4.12 +/- 0.45	6.69 +/- 0.73
Is difference significant?	No (p=0.409)	No (p=0.408)	Yes (p=0.003)

There appears to be no correlation between the differences in opposing legs and back pain. The amputee (3A) with the smallest difference reported back pain while the amputee (1A) with no back pain had significant differences between the amputated and non-amputated leg (Figures 4.11, 4.13, 4.15). This could be due to not having enough subjects but, on the other hand, may be due to no correlation between accelerations and back pain. Other factors such as leg length discrepancies and time since amputation could be the cause of the back pain.

Three out of six of the subjects had a leg length difference (Tables 4.6 - 4.7). Of the three that had a LLD, all three complained of back pain. This is in agreement with White, Lee, Giles, and Gofton who have implicated LLD as a possible source of back pain. Although acceleration patterns did not correlate with the LLD, the results obtained from creating an artificial LLD on all subjects were significant. A greater difference between opposing legs was seen for the controls when an LLD of 1 inch was created but the amputees did not show such an increase. The difference remained relatively the same as for the walking trials but the side with the maximum peak acceleration value changed. When the prosthesis was made too short (non-amputated leg on the board), the non-amputated leg had higher peak acceleration values than the amputated. This is in contrast to the walking trials where the amputated value was always higher. This increased acceleration for the side on the board could be due to the fact the leg will strike the ground earlier than expected leaving the subject with less time to adjust and prepare for heel strike.

Even though the difference increased for controls and the side of maximum peak acceleration changed for controls, the magnitude of the values did not change significantly. During the trials, subjects stated that when walking on the 1-inch boards they “felt” a difference. The ½ inch board did not evoke such a response, leading one to believe that a LLD of ½ inch or less might not be detectable to the subject but a difference of 1 inch or greater might cause concern.

6.0 Conclusions and Recommendations

This study has been an effective preliminary study that has shown that the accelerometer can be a useful tool in the analysis of amputee gait.

As a result of this research it was found that a high percentage of amputees experience back pain and the prevalence is higher than that of controls. It has shown that there is a difference between the acceleration patterns of amputees and non-amputees, but further research is needed to show that this difference is what causes the higher prevalence of back pain. The trend of side dominance and its increase with increased walking speed for amputees has been shown as well as a general population trend of increased acceleration of the spine with increased speed. In relation to walking speed, the study has also shown that the perception of speed among amputees is slower than that of controls. This study has also supported the notion that a difference in leg length could cause low back pain.

As a result of being a preliminary study several recommendations can be made as to follow-up suggestions. Recommendations include:

1. Recruiting more subjects to increase the value of the differences.
2. Transforming the accelerations into forces on the spine.
3. Attempt to balance out the acceleration differences seen in amputees.

    a. This will relate to proper fitting of prostheses, materials for prosthesis design, and proper rehabilitation and training for beginning prosthesis users.
4. Follow subjects for several months after the acceleration patterns are balanced.
    a. This will give a time history of unbalancing (if it occurs) and show the importance of proper fitting.
5. Use a motion analysis camera system to determine the precise time of highest acceleration and differences in gait
6. Several effects that can be evaluated are:
    a. Rehabilitation Differences
    b. Relationship between lateral location of pain and side of amputation
    c. Number of prostheses owned
    d. Number of times a return trip was made to the prosthetist
    e. Length of residual limb
7. Differences when performing other activities such as climbing stairs.

References

Author unknown. "Design Revision." www.me.dal.ca/~dp_03_8/rev2.html 5/05.

Author unknown. "G-Link Accelerometer." 2005 www.microstrain.com 5/05.

Author unknown. "Company Profile". Prosthetics-Orthotics Net. January 16, 2004.www.prostheitcs-orthotics.net 11/03.

Author unknown. "Amputation and Limb Deficiency". August 2003. http://biomed.brown.edu/courses/BI108.html 12/03.

Anderson GBJ, Ortengren R, Nachemson A. "Intradiskal pressure, intra-abdominal pressure and myoelectric back muscle activity related to posture and loading." *Clinical Orthopaedics and Related Research* 1977; 129:156-163.

Auvinet B, Berrut G, Touzard C, Moutel L, Collet N, Chaleil D, Barrey E. "Reference data for normal subjects obtained with an accelerometric device." *Gait and Posture* 2002; 16:124-134.

Bouten CV, Westertoerp KR, Verduin m, Janssen JD. " Assessment of energy expenditure for physical activity using a triaxial accelerometer." *Medical Science and Sports Exercise* 1994; 26:1516-1523.

Bridwell, K. "Vertebral Column." www.spineuniverse.com/displayarticle.php/article 1286.html 5/05.

Buckwalter, JA. "Soft tissue aging and musculoskeletal function." *Journal of Bone and Joint Surgery* 1993; 75A(10): 1533-1548.

Buckwalter, JA. “Aging and degeneration of the human intervertebral disc.” *Spine* 1995; 20(11): 1307-1314.

Burkart, AL, Beresford, WA. “The aging intervertebral disc.” *Physical Therapy* 1979; 59(8): 969-970.

Burke MJ, Roam V, Wright V. “Bone and joint changes in lower limb amputees.” *Annals of Rheumatoid Disorders* 1978; 37: 252-254.

Callaghan JP, Patla AE, McGill SM. “Low back three-dimensional joint forces, kinematics, and kinetics during walking.” *Clinical Biomechanics* 1999; 14:203-216.

Cappozzo A. “Compressive loads in the lumbar vertebral column during normal level walking.” *Journal of Orthopaedic Research* 1984; 1:292-301.

Capozzo A. “The forces and couples in the human trunk during level walking.” J*ournal of Biomechanics* 1983; 16:265-277.

Cromwell R, Schultz AB, Beck R, Warwick D. “Loads on the lumbar trunk during level walking.” *Journal of Orthopaedic Research* 1989; 7:371-377.

DiGiovine CP, Cooper RA, Wolf E, Fitzgerald SG, Boninger ML. “Analysis of whole body vibration during manual wheelchair propulsion: a comparison of seat cushions and back supports for individuals without a disability.” *Assistive Technology* 2003; 15(2): 129-144.

Dolan P, Adams MA. “Recent advances in lumbar spinal mechanics and their significance for modeling.” *Clinical Biomechanics* 2001; 16 Supplement:S8-S16.

Ehde DM, Smith DG, Czerniecki JM, Campbell KM, Malchow DM, Robinson LR. “Back pain as a secondary disability in persons with lower limb amputations.” *Archive of Physical Medicine and Rehabilitation* 2001; 82:731-734.

Farfan HF, et al. “The effects of torsion on the lumbar intervertebral joints: the role of torsion in the production of disc degeneration.” *Journal of Bone Joint Surgery* 1970; 52S: 468.

Freedman KB. “Herniated Nucleus Pulposus(Slipped Disc).” Back Pain Health Center, 2002.<

Friberg O. “ Clinical symptoms and biomechnics of lumbar spine and hip joint in leg length inequality.” *Spine* 1983; 8:643-651.

Friberg O. “Biomechanical significance of correct length of lower limb prostheses: a clinical and radiological study.” *Prosthetics and Orthotics International* 1984; 8:124-129.

Gilad I, Nissan M. “A study of vertebra and disc geometric relations of the human cervical and lumbar spine.” *Spine* 1986; 11(2): 154-157.

Giles LGF, Taylor JR. “Low back pain associated with leg length inequality.” *Spine* 1981; 6:510-521.

Gofton JP. “Persistant low back pain and leg length disparity.” *Journal of Rheumatology* 1985; 12:747-750.

Goh JH, Thambyah A, Bose K. “Effects of varying backpack loads on peak forces in the lumbosacral spine during walking.” *Clinical Biomechanics* 1998; 13 Supplement:S26-S31.

Gross RH. “Leg length inequality: how much is too much?” *Orthopedics* 1978; 1:307-310.

Henriksen M, Lund H, Moe-Nilssen R, Bliddal H, Danneskiod-Samsoe B. " Test – retest reliability of trunk accelerometric gait analysis." *Gait and Posture* 2003; 30:1-11.

Inman VT, Ralston HJ, Todd F. *Human Walking.* Baltimore: Williams and Wilkins, 1981.

Keller TS, Colloca CJ, Fuhr AW. "In Vivo transient vibration assessment of the normal human thoracolumbar spine." *Journal of Manipulative and Physiological Therapeutics* 2000; 23:521-530.

Khoo BC, Goh JH, Bose K. "A biomechanical model to determine lumbosacral loads during single stance phase in normal gait." *Medical Engineering Physiology* 1995; 17:27-35.

Koeller W, et al. "Biomechanical properties of human intervertebral discs subjected to axial dynamic compression – influence of age and degeneration." *Journal of Biomechanics* 1986; 19(10): 807-816.

Lee RY, Turner-Smith A. "The influence of the length of lower-limb prosthesis on spinal kinematics." *Archive of Physical Medicine and Rehabilitation* 2003; 84:1357-1362.

Lin HS, Liu YK, Adams KH. " Mechanical response of the lumbar intervertebral joint under physiological (complex) loading." *Journal of Bone and Joint Surgery* 1978; 60-A(1): 41-55.

Mansfield A, Lyons GM. " The use of acclerometery to detect heel contact events for use as a sensor in FES assisted walking." *Medical Engineering and Physics* 2003; 25:879-885.

Moe-Nilssen R. "A new method for evaluating motor control in real-life environmental conditions. Part 1: The instrument." *Clinical Biomechanics* 1998; 13:320-327.

Nachemson AL. “Low back pain: Its etiology and treatment.” *Clinical Medicine* 1971; Jan:18-23.

Nordin M, Frankel VH. *Basic Biomechanics of the Musculoskeletal System.* Maryland:Lippincott Williams and Wilkins, 2001.

Regan J. “Cervical Disc Herniation.” www.spinesource.com/back-pain-disorders/cervical-disc-herniation.html 5/05.

Richeimer S. “New Technologies for Treating Sciatica and Back Pain.” www.spineuniverse.com/article 1485.html. 5/05.

Robinson JL, Smidt GL, Arora JS. “Accelerographic, temporal, and distance gait factors in below-knee amputees.” *Pysical Therapy* 1977;57:898-904.

Smidt GL, Arora JS, Johnston RC. “Accelerographic analysis of several types of walking.” *American Journal of Physical Medicine* 1971;50:285-300.

Smith DG, Ehde DM, Legro MW, Reiber GE, del Aguila M, Boone DA. “Phantom limb, residual limb and back pain after lower extremity amputations.” *Clinical Orthopaedics and Related Research* 1999; 361:29-38.

Soukka A, Alaranta H, Tallroth K, Heliovaara M. “Leg length inequality in people of working age: the association between mild inequality and low back pain is questionable.” *Spine* 1991; 16:429-431.

White SC, Gilchrist LA, Wilk BE.” Asymmetric limb loading with true or simulated leg-length differences.” *Clinical Orthopaedics and Related Reseacrh* 2004;421:287-292.

Whittle MW. *Gait Analysis: an Introduction.* Oxford: Butterworth-Heinemann, 2002.

Yack HJ, Berger RC. “Dynamic stability in elderly: identifying a possible measure.” *Journal of Gerontology* 1993; 48:M225-230.

Yamada H. *Strength of Biological Materials.* New York: Robert E. Krieger, 1973.

Bibliography

Aday LA. *Designing and Conduction of Health Surveys, A Comp. Guide.* San Francisco: Jossey-Bass, 1996.

Author unknown. “Gross Anatomy: The Gait Cycle”. June 2005. www.upstate.edu/cdb/grossanat/limbs6.shtml 2000.

Author unknown. “Conventions for naming parts of the gait cycle”. June 2005. http://moon.ouhsc.edu/dthompso/gait/terms.htm March 2002.

Bates B. “A visual guide to physical examination.”

Hanada E, Kirby RL, Mitchell M, Swuste JM. “Measuring leg-length discrepancy by the “Iliac crest palpation and book correction” method: reliability and validity.” *Archives of Physical Medicine and Rehabilitation* 2001; 82:938-942.

Inman VT, Ralston HJ, Todd F. *Human Walking.* Baltimore: Williams and Wilkins, 1981.

Keeling P. “Is asymmetry in foot posture observed with LLD?”

Mann M, Glasheen-Wray M, Nyberg R. ”Therapist agreement for palpation and observation of iliac crest heights.” *Physical Therapy* 1984; 3:334-338.

McDowell I, Newell C. *Measuring Health: A Guide to Rating Scales and Questionnaires.* New York: Oxford University Press, 1996.

Moe-Nilssen R, Helbostad JL. “Interstride trunk acceleration variability but not step width variability can differentiate between fit and frail older adults.” *Gait Posture* 2005; 2:164-170.

Neumann DA. *Kinesiology of the Musculoskeletal System: Foundations for Physical Rehabiliatation*. St. Louis: Mosby, Inc., 2002.

Rosse C, Gaddum-Rosse P. *Hollinshead’s Textbook of Anatomy.* Philadelphia: Lippincott-Raven, 1997.

Whittle MW. *Gait Analysis: an introduction.* Great Britain: Butterworth-Heinemann, 2002.

Appendices

Appendix 1 Survey of Lower Limb Amputees

University of South Florida
School of Physical Education, Wellness, and Sport Studies
Department of Biomedical Engineering

Survey of Lower Limb Amputees

The purpose of this survey is to determine the frequency of different types of pain among lower limb amputees who use a prosthesis. This survey should take about 10-15 minutes to complete and answers are strictly confidential. Your input is greatly appreciated.

Directions: Please circle the answer that best applies to you and fill in the blank space when needed.

1. Age: _______________

2. Body weight in pounds (with prosthesis on): ___________

3. Height in inches: ____________

4. Gender
    a) Male
    b) Female

5. What is your present occupation? _______________

6. Are you currently taking any medication?
    a) Yes; List the medication and what it is used for.
    ____
    b) No

7. What type of prosthesis do you use? (Circle all that apply)
    a) Below the knee (BK Trans-Tibial)
    b) Above the knee (AK Trans-Femoral)
    c) None of the above

8. What side of the body is your lower limb prosthesis on?
    a) Left
    b) Right
    c) Both
    d) Not applicable

Appendix 1 (Continued)

9. Do you use any other type of prosthesis?
    a) Yes; What type is it? _____________
    b) No

10. What is the name of the manufacturer of the major parts of your prosthesis? Not the practitioner or facility where you were fit.
    ____

11. What is the weight of your prosthesis? _______________

12. What was the date of your amputation? If born without the limb put birth date.(month/year)____________

13. What was the date you were fitted for and started using your prosthesis? (month/year)____________

14. While you are awake, what percentage of the time do you wear your prosthesis?
    a) 0-25%
    b) 26-50%
    c) 51-75%
    d) 76-100%

15. What is the longest time you are able to stand still using your prosthesis?
    a) Up to 5 minutes
    b) 6 -10 minutes
    c) 11-20 minutes
    d) 21-45 minutes
    e) 46 minutes or more

16. What is the reason for your amputation?
    a) Medical condition other than cancer (Disease e.g., diabetes, vascular disease, etc.)
    b) Injury (Trauma)
    c) Congenital (Born without limb)
    d) Cancer (Tumor)
    e) Other_________________

17. Circle the best response for your activity level before using a prosthesis (if applicable).
    a) Activity restricted to daily living functions (eating, bathroom, etc.)
    b) Daily living functions and some community involvement
    c) Participation in community, vocational (job), therapeutic, and exercise activities
    d) Participation in high impact, stress or energy activities (i.e. running, cycling, team sports, etc.)
    e) No activity (used a caretaker)

18. Circle the best response for your activity level since using a prosthesis.
    a) Increased since obtaining a prosthetic
    b) Decreased since obtaining a prosthetic
    c) Remained the same since obtaining a prosthetic

19. What is your activity level now?
    a) Walking but restricted to level surfaces in and around the house
    b) Walking with the ability to go up curbs, stairs, etc. around the community
    c) Participation in vocational (job), therapeutic (healing), or exercise activities
    d) Participation in activities that exhibit high impact, stress or energy levels
    e) No walking or activity even with the aid of a prosthesis

20. How many days a week (0-7) do you participate in the following activities?
    Swimming_____________
    Weight Training________
    Running_______________
    Golf__________________
    Other_________________

21. How satisfied are you with your prosthesis?
    a) Very satisfied
    b) Satisfied
    c) Neither satisfied or dissatisfied
    d) Dissatisfied
    e) Very dissatisfied

Appendix 1 (Continued)

22. How satisfied were you with life in general before becoming an amputee?
   a) Very satisfied
   b) Satisfied
   c) Neither satisfied or dissatisfied
   d) Dissatisfied
   e) Very dissatisfied

23. How satisfied are you with life in general after becoming an amputee?
   a) Very satisfied
   b) Satisfied
   c) Neither satisfied or dissatisfied
   d) Dissatisfied
   e) Very dissatisfied

24. What do you consider as the main reason why you do not use your prosthesis?

   ____

25. Do you use any other device to assist you in walking? (i.e. cane, walker, crutches)
   a) Yes; What is it? __________________
   b) No

26. Do you experience back pain?
   a) Yes
   b) No

27. Do you have a medical condition or injury other than your amputation [scoliosis (curving of the spine to the side), lordosis (forward curving of the spine), car accident] that causes you to have back pain?
   a) Yes; What is the condition?__________________
   b) No

28. Rate the level of back pain you experience.

0	1	2	3	4	5
N/A	Little pain				Severe Pain

29. Where is the back pain located? ______________________

Appendix 1 (Continued)

30. Describe the nature of the back pain your experience. (i.e. throbbing, piercing, etc.) ____

31. In the last 4 weeks how often have you experienced back pain?
   a) Once or twice
   b) A few times
   c) Fairly often
   d) Very often
   e) Every day
   f) Not applicable

32. How much does the pain you experience interfere with the following things? Use the scale below:
   1) Not at all
   2) A little bit
   3) Moderately
   4) Quite a bit
   5) Extremely
   6) Not applicable

   a) Your ability to walk or move about ___________
   b) Your sleep ___________
   c) Your normal work ___________
   d) Your recreational activities ___________
   e) Your enjoyment of life ___________

33. Are you currently seeing a specialist specifically for the back pain other than your general practitioner? (i.e. chiropractor, rehabilitation specialist, surgeon, etc.)
   a) Yes; What kind? __________________
   b) No

34. Do you experience hip pain?
   a) Yes
   b) No

35. Rate the level of hip pain you experience.

0	1	2	3	4	5
N/A	Little pain				Severe Pain

Appendix 1 (Continued)

36. Do you experience “phantom pain”(actual pain)?
   a) Yes
   b) No

37. Rate the level of “phantom pain” you experience.

0	1	2	3	4	5
N/A	Little pain				Severe Pain

38. Do you experience “phantom sensation”(like pins and needles or like the limb is still there)?
   a) Yes
   b) No

39. Rate the level of “phantom sensation” you experience.

0	1	2	3	4	5
N/A	Little pain				Severe Pain

40. Do you experience any pain in the leg that has not been amputated?
   a) Yes
   b) No
   c) Not applicable

Thank you for completing the survey. Your input is greatly appreciated.
If you have any questions or concerns you can contact the following people:

Tracy Perrotti (813) 787-1246 uftray12@aol.com

Appendix 2 Control Group Survey

University of South Florida
College of Engineering
Department of Chemical Engineering/Biomedical Engineering

Survey of Back Pain

The purpose of this survey is to determine the prevalence of back pain among the general population. The survey should take about 10-15 minutes to complete and answers are strictly confidential. Your input is greatly appreciated.
Directions: Please circle the answer that best applies to you and fill in the blank space when needed.

1. Age: ___________________

2. Body weight in pounds: __________________

3. Height in inches: ______________________

4. Gender
   a) Male
   b) Female

5. What is your present occupation? ____________________

6. Are you currently taking any medication?
   a) Yes; List the medication and what it is used for.____________________
   b) No

7. Circle the best response for your activity level.
   a) Activity restricted to daily living functions (eating, bathroom, etc.)
   b) Daily living functions and some community involvement.
   c) Participation in community, vocational (job), therapeutic, and/or exercise activities.
   d) Participation in high impact, stress or energy activities (i.e. running, cycling, team sports, etc.)
   e) No activity (use a caretaker)

8. How many days a week (0-7) do you participate in the following activities?
   Swimming______________
   Weight Training__________
   Running________________

Appendix 2 (Continued)

Golf___________________
Other__________________

9. How satisfied are you with life in general?
    a) Very satisfied
    b) Satisfied
    c) Neither satisfied or dissatisfied
    d) Dissatisfied
    e) Very dissatisfied

10. Do you experience back pain?
    a) yes
    b) No

11. Do you have a medical condition or injury (scoliosis, lordosis, car accident etc.) that causes you to have back pain?
    a) Yes; What is the condition?___________________
    b) No

12. Rate the level of back pain you experience.

0	1	2	3	4	5
N/A	Little Pain				Severe Pain

13. Where is the back pain located? ___________________

14. Describe the nature of the back pain you experience. (i.e. throbbing, piercing, etc.)
____

15. In the last 4 weeks how often have you experienced back pain?
    a) Once or twice
    b) A few times
    c) Fairly often
    d) Very often
    e) Every day
    f) Not applicable

Appendix 2 (Continued)

16. How much does the pain you experience interfere with the following things?
    Use the scale below:
    1) Not at all
    2) A little bit
    3) Moderately
    4) Quite a bit
    5) Extremely
    6) Not applicable

    a) Your ability to walk or move about ___________
    b) Your sleep ___________
    c) Your normal work ___________
    d) Your recreational activities ___________
    e) Your enjoyment of life ___________

17. Are you currently seeing a specialist specifically for the back pain other than your general practitioner? (i.e. chiropractor, rehabilitation specialist, surgeon, etc.)
    a) Yes; What kind? ___________________
    b) No

18. Do you experience hip pain?
    a) Yes
    b) No

19. Rate the level of hip pain you experience.

0	1	2	3	4	5
N/A	Little Pain				Severe Pain

Thank you for completing the survey. Your input is greatly appreciated. If you have any questions or concerns you can contact the following people:

Tracy Perrotti (813) 787-1246
William E. Lee, Ph.D. (813) 974-2136

Appendix 3 G-Link Accelerometer Specifications

On-Board Accelerometers	Triaxial MEMS accelerometers, Analog Devices' ADXL2XXJE
Acceleration Range	+/- 2 G's or +/- 10 G's
Shock Limits	500 G's
Data Acquisition Modes	Mode 1: autotrigger, user specified as a programmable output voltage from a specific channel Mode 2: on command from RS-232 or RF link Mode 3: transmit continually for pre-programmed time period
DAS Software	Windows 95/98/2000/XP, PC compatible
Analog to Digital (A/D) Converter	Successive approximation type, 12 bits resolution
Data Storage Capacity	2 megabytes (approximately 1 million data points), 8 megabytes optional
Datalogging Sample Rate	Programmable, from 32 to 2048 sweeps/second (one sweep represents one sample from all active channels)
Continuous Transmission Sample Rate	1000 sweeps of all three channels per second
Data Sample Duration	Programmable from 1 to 65,535 data sweeps; for 2048 sweeps per second, sample duration is 32 seconds
G-Link Node Input Power	3.6 volt lithium ion AA size internal battery recommended, 2400 milliamp-hour capacity standard; or customer may supply external power from 3.1 to 9 volts
G-Link Battery Lifespan	273 hours (estimated, using 80% @ 6 milliamps current draw and sensor RF receive link active, 20% @ 20 milliamps w/ sensor RF transmit link active)
Radio Frequency (RF)Transceiver Carrier	916 MHz, narrowband, FCC compliant, license free use in USA
Range for Base Station RF Trigger	100 feet (30 meters) typical, line of sight
Range for Bi-Directional RF Link	100 feet typical, line of sight
RF Programming and Downloading	19200 baud, wireless RF, pulse code modulated, ASK
RS-232 Programming and Downloading	38400 baud direct serial RS-232 cable w/ miniature connector
G-Link Sensor Transceiver PCB Size	25 mm by 25 mm by 5 mm
Base Station Enclosure Size	110 mm by 75mm by 25 mm
Operating Temperature	-40 to +85 degrees Celsius

Appendix 4 Information Cover Sheet

Information for People Who Take Part in the Survey for an Investigation into the Prevalence of Back Pain in Lower Limb Amputees

---

The following information is being presented to help you decide whether or not you want to take part in a minimal risk research study. Please read this carefully. If you do not understand anything, ask the person in charge of the study.
Title of Study: Investigation into the Prevalence of Back Pain in Lower Limb Amputees
Principal Investigator: Tracy A. Perrotti
Study Location(s): University of South Florida
You are being asked to participate because you are an amputee.

General Information about the Research Study

The purpose of this research study is to determine the prevalence of back pain among lower limb amputees who use a prosthesis. The information collected and the results obtained will be used to complete a master's thesis requirement and may be published.

Plan of Study

You will be required to complete a 40-question survey and return it in the enclosed self addressed stamped envelope. The survey should take between 10-15 minutes to complete.

Payment for Participation

No funds are available for this study. None of the people involved in the study, including the researchers, will be paid.

Benefits of Being a Part of this Research Study

By taking part in this research study, you may increase our overall knowledge of the prevalence of back pain among amputees. This information may help improve the design of new prostheses and the rehabilitation processes. There are no immediate benefits to you.

Risks of Being a Part of this Research Study

There are no risks involved in participating in this study.

Confidentiality of Your Records

Your privacy and research records will be kept confidential to the extent of the law. Authorized research personnel, employees of the Department of Health and

Human Services, and the USF Institutional Review Board may inspect the records from this research project.

The results of this study may be published. However, the data obtained from you will be combined with data from others in the publication. The published results will not include your name or any other information that would personally identify you in any way.
The results of this study will be used to meet a master's thesis requirement. Only those involved with the thesis will have access to the information obtained from you.

Volunteering to Be Part of this Research Study

Your decision to participate in this research study is completely voluntary. You are free to participate in this research study or to withdraw at any time. There will be no penalty or loss of benefits you are entitled to receive, if you stop taking part in the study.

Questions and Contacts

- If you have any questions about this research study, contact:

  Tracy Perrotti (813) 787-1246

- If you have questions about your rights as a person who is taking part in a research study, you may contact the Division of Research Compliance of the University of South Florida at (813) 974-5638.

Appendix 5 Excel Spreadsheet of Amputee Survey Results

Subject #	Age (years)	Weight (lbs)	Height(in)	Gender	Occu-pation	Take Medi-cation?	Med 1	Med 2
1	52	272	77	m	a	a	f	
2	36	200	74	m	g	b		
3	37	137	60	f	f	a	a	
4	27	105	56	f	g	b		
5	66	165	67	m	b	a	h	l
6	41	156	65	f	h	b		
7	81	123	70	m	b	a	n	l
8	63	106	63.5	f	f	a	b	i
9	44	190	78	m		b		
10	78	195	69	m	b	a	m	g
11	55		66	f	e	a	l	j
12	56	150	67	f	ss	a		
13	88	160	69	m	b	a	h	f
14	70		62	f	b	a		
15	83	217	62	f	b	a	p	q
16	55	120	61	f		a	i	h
17	37	155	66.5	f	c	a	b	
18	51	155	67	m	a	a	q	g
19	29	115	62	f	e	b		
20	56	203	73	m	d	b		
21	58	171	71	m	b	a	f	f
22	46	175	72	m	h	b		
23	36	289		f	i	b		
24	44	290	70	m	f	a	g	
25	27	123	68	m	i	a	c	c
26	59	245	78	m	a	a	o	g
27	58	260	70	m	h	a	h	
28	35	140	62.5	f	g	a	j	
29	22	140	64	f	d	b	j	j
30	33	133	69	f	c	b		
31	39	190	67	m	i	b		
32	47	185	57	m	b	a	d	h
33	55	165		m	e	b		
34	39	107	62	f	f	a	i	k

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Subject #	Age (years)	Weight (lbs)	Height(in)	Gender	Occu-pation	Take Medi-cation?	Med 1	Med 2
35	54	170	64	f	h	a	n	
36	52	275	75	m	i	a	j	j
37	81	110	58	f	b	a	d	q
38	49	285		m	i	a	f	
39	50	200	65	f	i	a	q	f
40	15	133	57	m	d	b	f	
41	35	140	68	f	a	a	a	
42	35	207	70	m	i	b		
43	50	167	61	f	a	a	p	f
44	37	210	75	m	i	a	j	
45	40	125	36	m	h	b		
46	60	165	70	m	b	b		
47	44	145	65	f	i	b		
48	56	200	75	m	g	a	i	h
49	45	139	67	f	g	a	j	
50	42	190	60	m	h	a	m	q
51	74	299	70	m	b	a	n	
52	56	320	74	m	b	a	l	n
53	66	225	76	m	b	a	d	q
54	83	185	75	m	b	a		
55	58	256	76	m	a	a	o	j

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Subject #	Med 3	Type of Pros-thesis	Side Pros-thesis is on	Use any other Pros-thesis?	Manu-facturer	Weight (lbs) pros-thesis	Date of Amp-utation	Date Fitted
1		a	b	b	a	8	Jan-99	Jun-99
2		b	a	b	b	5	May-04	Jul-04
3		a	b	b			Jan-80	Jan-80
4		b	b	b	c	6	Feb-77	Apr-78
5		b	a	b	c	10	Mar-97	Jun-98
6		a	b	b	d	3.5	Mar-85	Jun-86
7	q	b	a	b			Mar-04	Mar-04
8		a	b	b		2.5	Jan-90	Mar-90
9		a	b		e	2	Jul-04	Apr-04
10	l	b	c	b				
11	g	a	b	b	e	3	Nov-98	Jan-98
12		b	a	b		7	Jan-91	Jan-92
13	f	b	b	b		9	Oct-84	Apr-85
14		b	a	b			Aug-04	
15	q	a	b	a				
16	j	b	c	b		60	Dec-77	Jul-81
17		b	a	b	n	8	Apr-78	May-78
18		b	c	b	c	10	Apr-03	Oct-03
19		b	b	b		8	Jan-77	Jan-77
20		a	c	a	a	4.5	Feb-00	Jun-00
21	a	a,b	c	b	c	13	Mar-04	mar-01, may-01
22		b	a	a	a	11	Aug-84	Nov-84
23		b	b	b	c	15	Oct-02	Oct-02
24		a	a	b	f	5	Oct-00	Jan-01
25		b	b	b	g,c	8	Nov-96	Aug-98
26		b	a	b		8	Oct-03	Nov-03
27		b	b		g	15	Sep-94	Dec-94
28		a	a	b	c	4	Jan-70	Nov-05
29		b	b	b	g		Jan-83	
30		a	a	b	i	5	Jan-76	July-76
31		b		b	j		Jan-85	Jan-87
32		a	b	b		8	Mar-04	May-04
33		a	b	b		6	Feb-00	Jan-60
34	k	a	a	b	k	4	Sep-02	Jan-03

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Subject #	Med 3	Type of Pros-thesis	Side Pros-thesis is on	Use any other Pros-thesis?	Manu-facturer	Weight (lbs) pros-thesis	Date of Amp-utation	Date Fitted
35		a	b	b	c	5	Feb-03	Apr-04
36	g	a	c	b			july-99, jun-01	sept-01
37	i	a	a	b		6	Feb-93	Aug-93
38		a	b	b			Jul-04	Sep-04
39		a	b	b		14	Dec-92	Apr-93
40		a	b	b	c	4	Jul-89	Mar-90
41		b	b	b			Jun-69	May-05
42		a	b	b	g	3	Oct-01	Dec-01
43		a	b	b		6	Oct-04	Jan-04
44		a,b	c	b	c	17	Mar-98	Mar-99
45		c	d	b			May-99	
46		b	a	b	c,m	6.5	Feb-96	Mar-96
47		a	a	b	d	4	Jun-87	Oct-87
48	m	a	a	b		12	Jul-73	Jan-74
49		b	a	b	c	10	Mar-00	Jun-00
50		b	a	b	c,g	9	Aug-90	Sep-90
51		a	a	b	n	14	Nov-55	Feb-56
52		a	a	b			May-02	Jul-02
53	f	a	b	a			Aug-02	Nov-02
54		a	b	b			Apr-97	Nov-97
55	l	a	a	b	g	10	Jul-03	Jan-03

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Subject #	% of time use pros-thesis	Longest time able to use	Reason for Ampu-tation	Activity Level before Pros-thesis	Activity Level Since using Prosthesis	Activity Level Now	How many days swim	How many days weight train
1	d	c	a	c	b	b	0	1
2	d	e	b	c	b	c	1	0
3	d	e	a	d	a	d	3	3
4	d	e	c	d	a	c	1	2
5	c	e	a	c	b	b	2	0
6	d	e	b	d	a	d	0	6
7	c	e	a	c	c	b	0	0
8	d	e	d	c	a	c	0	0
9	c	e	a	a	b	b	0	0
10	a	a	a	c	b	e	0	0
11	d	a	a	c	b	a	0	0
12	d	c	a	d	a	b	0	0
13	d	a	a	c	b	e	0	0
14	a	b	a	a	c	e	1	0
15			a	b				
16	a	a	b	a	a	a	3	0
17	d	d	d	e	a	c	0	3
18	d	c	b	d	b	a	1	7
19	d	e	c			d	1	1
20	c	d	b	c	b	b	1	5
21	c	e	e	c	a	c	1	4
22	c	e	b	d	b	c	2	3
23	b	c	b	a	a	a	3	3
24	d	e	b	d	b	c	1	0
25	c	b	d	d	b	b	0	0
26	c	e	b	c	b	b	0	0
27	c	d	b	b	c	b	0	0
28	d	e	e			d	0	0
29	d	e	c	c	c	d	0	2
30	d	e	b	b	c	c	2	2
31	d	c	b	b	b	b	0	0
32	d	d	a	b	a	a	2	7
33	d	e	b	d	c	d	0	2
34	d	e	a	d	b	b	0	0

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Subject #	% of time use pros-thesis	Longest time able to use	Reason for Ampu-tation	Activity Level before Pros-thesis	Activity Level Since using Prosthesis	Activity Level Now	How many days swim	How many days weight train
35	d	c	b	b	a	b	0	0
36	d	d	a	d	b	b	0	0
37	c	e	a	b	b	b	0	0
38	c	a	b	c	a	b	0	2
39	d	c	a	a	a	b	0	0
40	c	d	c	b	a	c	0	0
41	d	b	c			b	0	2
42	d	e	b	d	c	d	0	0
43	d	c	b	b	a	b	0	3
44	a	d	b	c	b	c	0	0
45			b	d			0	2
46	c	e	a	c	b	c	2	0
47	d	c	b	d	c	d	0	3
48	d	c	b	d	b	b	0	0
49	d	e	d	c	c	c	0	0
50	c	e	b	d	b	c	0	0
51	d	e	b		c	b	0	0
52	d	d	a	b	a	b	0	0
53	a	b	e	a	c	a	0	0
54	d	e	a	c	b	a	0	0
55	a	c	a	b	b	b	0	0

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Subject #	How many days run	How many days golf	How many days do other activity	What is other Activity	Satisfaction with Pros-thesis	Satis-faction with life before pros-thesis	Satis-faction with life after pros-thesis	Main reason do not use pros-thesis
1	0	0		a	b	b	d	
2	0	0	5	e	b	a	b	a
3	0	0	0		d	c	a	
4	0	0	2	b	a	a	a	b
5	0	0	7		b	a	b	a
6	0	0	7	c	b	a	a	
7	0	0	0		a	a	b	
8	0	0	7	a	b	a	b	
9	0	0	0		a	a	a	
10	0	0	7	f	a	a	b	f
11	0	0	0		b	a	e	
12	0	0	0		c	b	c	
13	0	0	0		d	a	b	c
14	0	0	0		c	b	c	d
15						a	b	
16	0	0	0		d	a	d	c
17	0	1	0		a	e	a	
18	1	1	3	f	b	a	c	b
19	1	1			b		a	
20	1	1	7	a	b	a	b	
21	1	1			a	b	a	f
22	1	1	5	a	c	a	c	d
23	1	1			b	a	b	e
24	0	1		f	a	a	b	b
25	0	0		f	d	a	b	b
26	0	0			a	a	e	
27	0	0	6	a	d	a	b	c,d
28	0	0	1,7	d,f	a			
29	1	0			b	c	a	
30	0	0		b,f	b	a	b	
31	0	0		e	c	c	e	
32	0	0		f	d	b		
33	0	0			d	a	b	
34	0	0			c	a	d	

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Subject #	How many days run	How many days golf	How many days do other activity	What is other Activity	Satisfaction with Pros-thesis	Satis-faction with life before pros-thesis	Satis-faction with life after pros-thesis	Main reason do not use pros-thesis
35	0	0			b	a	b	
36	0	0			b	a	e	b,d
37	0	0		f	c	a	d	d
38	0	0			a	a	a	
39	0	0	2	e	c	a	d	
40	0	0			c	c	c	
41	0	0			b			
42	0	0	2	c	b	b	c	
43	0	0	3	f	d	d	b	
44	0	0			b	b	e	b
45	0	0						
46	0	0		f	e	a	b	c
47	6	0	6	c,f	a	a	b	b
48	0	0	2	a	b	a	b	
49	0	0			b	a	a	
50	0	1			c	a	a	b,d
51	0	1			a	a	a	
52	0	0			b	a	c	
53	0	0			c	a	e	c,d
54	0	0			e	a		
55	0	0	1	f	d	a	d	b,d

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Subject #	Use another assist device	other assist device	exp-erience back pain	Medical Condition that causes pain	What is it	Level of back pain	Pain Location	Nature of Pain
1	a	a	a	b		4	f	a
2	b		b	b		0		
3	b		a	a		3	a,b	b
4	b		a	a	a	4	a	b,c
5	a		a	a	b	2	a	c
6	b		a	a	c	4	a	c
7	a	a	b	b		0		
8	b		a	b		3	a	b
9	b		b	b		0		
10	a	b	b	b		0		
11	a	a	a	b		4	a	b,c
12	a	a	a	b		4	c	d
13	a	a,b	b	b		0		
14	a	b	a	a	d	3	c	b,h
15				b				
16	a	a,b	a	b		3	a	b
17			b	b		0		
18	a	c	a	b		2	a	b
19	b		a	b		3	a	b
20	a	c	a	b		2	a,d	e
21	a	a	b	b		1		
22	b		a	b			a	e
23	a	a	a	b		3	a	b,f
24	b		a	b		2	a	b,e
25	a	c	a	b		1	a	
26	a	a	b	b				
27	a	a	a	b		2	a,d	b
28	b		a	a	e	3	a	a,c
29	b		a	a	e	1	a	a
30	b		b	b		0		
31	b		a	a	c	5	a	g
32	a	a	a	b		4	f	a,c
33	b		a	b		2	a	h
34	a	a	b	b		0		

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Subject #	Use another assist device	other assist device	exp-erience back pain	Medical Condition that causes pain	What is it	Level of back pain	Pain Location	Nature of Pain
35	b		a	b		1	a	b
36	b		a	b		4	a	b,h
37	a	a	a	b		1	a	a
38	a	a	a	a	a	4	a	
39	b		a	b		5	a	c
40	a	d	b	b		1		
41	b		a	b		4	a	h
42	b		b	b		1		
43	a	b	a	a	a,c	3	a	c,f
44	b		b	b		0		
45	b		b	b				
46	a	c	b	b		1		
47	b		b	b				
48	s	c	a	b		2	a	h
49	b		a	b		3	a	
50	a	c	a	b		2	a	b
51	b		b	a	f	4		h
52	a		a	a	a	3	a	a
53	b		b	a	f	5		
54	a	a	b			1		
55	b		b	b		0		

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Subject #	Pain in last 4 weeks	Pain interfere with walking	Pain interfere with sleep	pain interfere with normal work	Pain interfere with rec activities	Pain interfere with enjoy-ment of life	Seeing a specialist for back pain	What kind of specialist
1	d	3	2	4	5	4	b	
2	f	1	1	1	1	1	b	
3	e	4	2	5	5	2	b	
4	e	3	3	1	3	1	b	
5	b	2	2	2	2	2	b	
6	e	2	2	2	2	2	b	
7							b	
8	c							
9	f	6	6	6	6	6	b	
10	f	6	6	6	6	6	a	a
11	d	5	1	5	6	5	b	
12	c	4	1	3	1	1	b	
13	f	6	6	6	6	6	b	
14	c	0	3	0	3	0	b	
15	f					3		
16	d	3	4	4	4	4	b	
17	f	6	6	6	6	6	b	
18	a	1	3	2	1	3	a	a
19	d	2	1	2	2	2	b	
20	b	2	1	1	1	2	b	b
21		1	1	1	1	1	b	
22	c	2	2	2	3	3	b	
23	c	4	2	5	4	3	b	
24	d	2	1	2	2	2	b	
25	b	2	1	2	2	2	a	c
26	f	6	6	6	6	6	b	
27	c	4	3	3	4	4	b	
28	c	3	5	3	4	5	a	a,b,d
29	b	2	1	1	2	1	b	
30	f	1	1	1	1	1	b	
31	e	4	2	2	5	5	a	b
32	e	4	5	5	5	5	a	b
33	e	2	1	2	2	2	b	
34	f	6	6	6	6	6	b	

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Subject #	Pain in last 4 weeks	Pain interfere with walking	Pain interfere with sleep	pain interfere with normal work	Pain interfere with rec activities	Pain interfere with enjoy-ment of life	Seeing a specialist for back pain	What kind of specialist
35	b	2	2	1	2	3	b	
36	b	3	3	4	5	4	b	
37	b	2	1	2	3	2	b	
38	b	2	2	3	4	3	a	a
39	e	5	5	5	5	5	b	
40		2	1	2	2	2	b	
41	c	4	3	4	4	4	b	
42	a	1	2	1	1	2	b	
43	e	3	5	3	2	2	a	a,d
44	a	1	1	1	1	1	a	
45	a	1	1	1	1	1	b	
46	f	2	1	2	2	2	b	
47	f	6	6	6	6	6		
48	e	2	2	2	2	2	b	
49	c	5	4	7	7	3	a	a
50	c	1	2	2	2	2	b	
51	a	4	2	4	4	4	b	
52	d	2	2	6	2	2	b	
53	f	1	1	1	1	1	b	
54	f	6	6	6	6	6	b	
55	f	1	1	1	1	1	b	

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Subject #	Experience hip pain	Level of Hip Pain	Experience phantom pain	Level of Phantom Pain	Experience Phantom Sensation	Level of Phantom Sensation	Pain in non-amputated Leg
1	b	0	a	4	a	4	a
2	b	0	a	1	a	4	b
3	a	3	a	4	b	0	a
4	a	4	b	0	b	0	a
5	b	0	a	3	a	3	b
6	a	4	b	0	b	0	c
7	a	3	a	3	a	2	b
8							
9	a	2	a	2	b	2	b
10	b	0	a	1	a	1	c
11	b	0	a	4	a	4	b
12	b	0	a	5	b	0	a
13	b	0	a	4	a	4	b
14	a	1	a	5	a	5	b
15			a	4	a	5	b
16	b	0	b	0	b	0	b
17	b	0	a	1	a	3	b
18	a	1	b	0	a	2	c
19	b	0	b	0	b	0	b
20	b	1	a	3	a	3	c
21	b	0	b	0	a	3	c
22	a		a		a		b
23	a	3	a	5	a	4	a
24	a	1	b	0	a	2	b
25	b	0	a	5	a	3	a
26	b		b		a	4	b
27	b		a		a	1	b
28	a	1	b	0	b	0	a
29	b	0	b	0	b	0	a
30	b	0	b	0	b	0	b
31	a	2	a	3	a	3	b
32	a	4	a	5	a	5	a
33	b	0	a	2	a	2	a
34	a	1	a	1	a	3	b

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Subject #	Experience hip pain	Level of Hip Pain	Experience phantom pain	Level of Phantom Pain	Experience Phantom Sensation	Level of Phantom Sensation	Pain in non-amputated Leg
35	b	1	a	4	a	4	b
36	b	0	a	1	a	2	c
37	a	1	a	2	a	3	b
38	a	3	a	6	a	5	a
39	a	5	a	4	a	4	a
40	a	3	a	2	a	2	a
41	a	5	b	0	b	0	a
42	b	0	a	1	a	4	b
43	a	4	a	5	a	5	b
44	b	0	a	3	a	1	c
45	b		b		a		b
46	b	2	a	2	a	4	a
47			a		a	5	b
48	a	2	a	2	a	2	a
49	a	3	a	3	a	3	b
50	b	0	a	2	a	2	a
51	a	4	a	4	b		b
52	a	3	a	2	a	4	a
53	b	3	a	5	a	5	a
54	b	1	a	4	a	4	a
55	a	2	a	5	a	5	a

Note: See Appendix 1 for survey questions and answers.
Answer Key included at end of Appendix 5.

Appendix 5 (Continued)

Key for Survey Answers

Occupations
a) Disabled
b) Retired
c) Homemaker
d) Student
e) Teacher
f) Nurse
g) Administration/Managerial
h) Professional
i) Other

Medications
a) Anti-inflammatory
b) Migraine
c) Skin Care
d) Circulation
e) Cancer
f) Pain
g) Cholesterol
h) Blood pressure
i) Osteoporosis/arthritis
j) Anxiety/depression
k) Organ rejection
l) Diabetes

Reasons for Non-Prosthesis Use
a) Fatigue
b) Wounds/Sores/Skin Problems
c) Doesn't Fit/ Bad fit
d) Pain
e) Cumbersome
f) Other

Other Assistive Devices
a) Cane
b) Walker
c) Crutches
d) Wheelchair
e) Other

Nature of Back Pain
a) Piercing
b) Ache
c) Throb
d) Stabbing
e) Stiffness
f) Burning
g) Cramping

Location of Back Pain
a) Lower back
b) Neck
c) Sacroiliac
d) Mid Back
e) Between Shoulder Blades
f) Above Hips

Medical Condition that Causes Back Pain (other than amputation)
a) Fracture/dislocation/deformation of hip or leg
b) Diabetes
c) Car accident
d) Arthritis
e) Scoliosis/spondylosis/lordosis

Type of Specialist
a) Chiropractor
b) PT/rehab specialist
c) Acupuncturist
d) Surgeon

Manufacturer
a) Hanger
b) CA Tech
c) Otto Bock
d) Flex Foot
e) West Coast
f) Ohio Willowood
g) Ossur
h) Mauch
i) Seattle Light
j) Brownsfield
k) Elation
l) Luxon
m) Endolite

Other Activities
a) Walking
b) Pilate's/Yoga
c) Cycling
d) Team Sports
e) Yard/House Work
f) Other

Appendix 6 Excel Spreadsheet of Survey Results for Controls

Subject #	Age	Weight (pounds)	Height (inches)	Gender	Occu-pation	Take Medicines?	Med 1	Med 2
1	50	165	63	f	g	b		
2	46	210	70.5	m	i	b		
3	38	160	71	m	h	b		
4	24	120	60	f	g	a	loestrin	
5	57	170	69	m	h	a	g	
6	31	233	72	m	d	a	q	
7	48	234	73	m	g	b		
8	22	160	68	m	d	b		
9	26	119	63	f	e	a	r	
10	70	170	72	m	b	a	h	g
11	44	245	74	m	e	a	j	
12	24	140	63	f	e	b		
13	31	108	62	f	e	a	q	
14	30	215	70	m	e	a	h	
15	31	124	64	f	e	a	q	
16	50	165	67	f	d	b		
17	26	126	61	f	e	b		
18	49	150	64	f	e	a	q	
19	39	186	72	m	e	b		
20	54	180	65	f	g	b		

Note: See Appendix 2 for survey questions and answers.
Answer Key included at end of Appendix 6.

Appendix 6 (Continued)

Subject #	Age	Weight (pounds)	Height (inches)	Gender	Occupation	Take Medicines?	Med 1	Med 2
21	24	120	67	f	e	a	r	
22	49	125	64	f	e	a	q	m
23	63	135	64	f	e	b		
24	54	140	63	f	e	a	q	botox
25	19	235	70	m	d	b		
26	18	145	72	m	d	a	q	q
27	18	136	66	f	d	b		
28	46	168	69.5	f	g	a	q	
29	62	140	66	f	g	a	h	
30	51	175	68	f	g	a	f	q
31	31	190	69	m	g	b		
32	46	275	75	m	i	a	h	
33	24	180	68.5	m	d	b		
34	21	150	66	f	d	b		
35	25	122	64	f	d	b		
36	23	175	70	m	d	b		
37	35	190	71	m	d	b		
38	26	175	70	m	d	b		
39	19	137	68	f	g	a	q	
40	19	125	64	f	g	b		
41	30	225	72	m	h	a	f	
42	28	230	75	m	h	b		
43	27	160	68	f	g	b		
44	30	230	76	m	h	a	h	

Note: See Appendix 2 for survey questions and answers.
Answer Key included at end of Appendix 6.

Appendix 6 (Continued)

Subject #	Med 3	Activity Level	How many days a week do you swim?	How many days a week do you weight train	How many days a week do you run?	How many days a week do you golf?	How many days a week do you do another activity?	What is the other activity?
1		c	0	0	0	0	5	
2		c	0	0	0	0	2	home projects
3		c	0	2	2	0	0	
4		c	0	0	0	0	0	
5		b	0	0	0	0	0	
6		b	1	0	0	0	4	walking
7		c	0	0	3	1	1	
8		d	0	6	0	0	0	
9		c	0	0	0	0	0	
10	m	c	0	7	0	0	7	walking
11		c	0	0	0	0	5	motorcycle
12		c	0	2	0	0	3	
13		c	0	3	0	0	5	walking
14		c	0	0	0	0	3	
15		c	0	0	0	0	3	dance
16		d	0	3	0	2	6	
17		d	0	2	3	0	0	
18		c	0	0	0	0	7	walk/bike
19		d	0	0	4	0	0	
20		c	0	0	0	0	4	walking

Note: See Appendix 2 for survey questions and answers.
Answer Key included at end of Appendix 6.

Appendix 6 (Continued)

Subject #	Med 3	Activity Level	How many days a week do you swim?	How many days a week do you weight train	How many days a week do you run?	How many days a week do you golf?	How many days a week do you do another activity?	What is the other activity?
21		c	0	4	0	1	0	
22		b	0	0	0	0	0	
23		c	0	0	0	0		walking/gardening
24		b	0	0	0	0	7	
25		d	0	0	1	0	1	football/fencing
26		a	0	0	0	0	1	
27		a	0	1	0	0	2	
28		c	0	0	0	0	2	tennis
29		c	0	0	0	0	4	walking
30		c	0	0	0	0	7	walking/cleaning
31		d	0.5	2	1	0	1	
32		d	0	0	0	0	2	tennis,walk
33		a	0	0	0	0	0	
34		c	0	2	4	0	0	
35		c	0	0	0	0	0	
36		d	0	4	7	0	7	
37		d	0	3	3	0		tennis
38		d		3	2			
39		b	0	0	0	0	0	
40		c	0	0	3	0	0	
41		c	0	0	0	0	0	
42		a	0	0	0	0	0	
43		c	0	0	0	0	0	
44		d	0	0	3	0	0	

Note: See Appendix 2 for survey questions and answers.
Answer Key included at end of Appendix 6.

Appendix 6 (Continued)

Subject #	Satisfaction with life	Experience back pain?	Do you have a medical condition that causes the pain?	What is the medical Condition	Level of back pain	pain location	nature of pain
1	b	b	b		0		
2	c	a	b		1	a	b
3	b	b	b		0		
4	c	a	b		3	a	a,b
5	a	b	b		1		
6	a	a	b		2	a	a
7	b	a	a	d	2	a	a
8	a	b	b		0		
9	b	b	b		0		
10	a	b	b		0		
11	b	a	a	d	4	a	a
12	c	b	b		0		
13	b	b	b		0		
14	b	b	b		0		
15	c	a	a	e	2	a	
16	a	b	b		0		
17	b	b	a	e	1	a	a
18	b	b	b		1	a	b
19	d	a	b		5	a	c
20	b	a	b		1	a	a

Note: See Appendix 2 for survey questions and answers.
Answer Key included at end of Appendix 6.

Appendix 6 (Continued)

Subject #	Satisfaction with life	Experience back pain?	Do you have a medical condition that causes the pain?	What is the medical Condition	Level of back pain	pain location	nature of pain
21	b	b	b		1	a	a
22	a	a	a	e	3	b	b
23	a	a	b		2	a	c
24	d	a	a	e,f	5	a,f	d,f
25	a	b	b		0		
26	b	a	b		1	a	I
27	c	b	b		0		
28	b	b	b		0		
29	a	a	b		3	a	j
30	b	a	a	f	2	a,b	a
31	b	a	a		2	a	a
32	b	a	b		3	a	b
33	c	b	b		0		
34	b	a	a	c	3	a	a
35	b	a	b		4	d,e	c
36	b	b	b		0		
37	b	a	b		1	a	a
38	a	b	b		1		
39	b	a	a	c	3	a,d	c
40	b	b	b		0		
41	b	a	b		1	a	
42	a	b	b		0		
43	a	b	b		0		
44	a	a	b		2	a	c

Note: See Appendix 2 for survey questions and answers.
Answer Key included at end of Appendix 6.

Appendix 6 (Continued)

Subject #	Pain in the last 4 weeks	Pain interfere with walking	Pain interfere with sleep	Pain interfere with normal work	Pain interfere with rec activities
1	f	6	6	6	6
2	a	1	1	1	1
3	f	6	6	6	6
4	c	2	2	1	1
5	f	1	1	1	1
6	a	1	2	1	1
7	a	1	2	1	2
8	f	1	1	1	1
9	f	1	1	1	1
10	f	6	6	6	6
11	a	5	4	5	5
12	f	6	6	6	6
13	f				
14	f	1	1	1	1
15	b	2	3	3	2
16	f	6	6	6	6
17	a	1	1	1	1
18	a	1	2	1	1
19	d	0	0	0	2
20	a	1	1	1	1

Note: See Appendix 2 for survey questions and answers.
Answer Key included at end of Appendix 6.

Appemdix 6 (Continued)

Subject #	Pain in the last 4 weeks	Pain interfere with walking	Pain interfere with sleep	Pain interfere with normal work	Pain interfere with rec activities
21	b	1	1	1	2
22	b	1	1	2	2
23	b	1	3	1	1
24	e	5	4	5	4
25	f	1	1	1	1
26	a	1	1	1	1
27	f	6	6	6	6
28	f	6	6	6	6
29	b	2	2	2	3
30	e	2	2	2	2
31	e	1	2	2	2
32	c	2	3	2	2
33	f	1	1	1	1
34	b	1	3	2	2
35	c	1	4	1	1
36	f	1	1	1	1
37	a	1	1	1	2
38	f				
39	c	2	3	2	1
40	f	6	6	6	6
41	b	5	3	2	2
42	f	6	6	6	6
43	f	6	6	6	6
44	a	1	1	1	1

Note: See Appendix 2 for survey questions and answers.
Answer Key included at end of Appendix 6.

Appendix 6 (Continued)

Subject #	Pain interfere with enjoyment of life	Seeing a specialist for the pain	What kind of specialist	Experience hip pain?	Level of hip pain
1	6	b		b	0
2	1	b		b	0
3	6	b		b	0
4	2	b		b	0
5	1	b		a	2
6	1	b		b	0
7	1	a	e	a	2
8	1	b		b	0
9	1	b		b	0
10	6	b		b	0
11	5	b		b	0
12	6	b		b	0
13					
14	1	b		b	0
15	3	b		a	2
16	6	b		a	1
17	1	b		b	0
18	2	b		a	2
19	0	b		b	0
20	1	b		b	0

Note: See Appendix 2 for survey questions and answers.
Answer Key included at end of Appendix 6.

Appendix 6 (Continued)

Subject #	Pain interfere with enjoyment of life	Seeing a specialist for the pain	What kind of specialist	Experience hip pain?	Level of hip pain
21	2	b		b	0
22	2	b		b	0
23	1	a	a	b	0
24	5	a	e	a	5
25	1	b		a	1
26	1	b		b	0
27	6	b		b	0
28	6	b		b	0
29	3	b		b	0
30	2	b		b	0
31	3	b		b	1
32	2	b		b	0
33	1	b		b	0
34	2	b		b	0
35	1	b		a	1
36	1	b		b	0
37	1	b		b	0
38					
39	1	b		b	0
40	6	b		b	0
41	2	b		b	2
42	6	a		b	0
43	6	b		b	0
44	1	b		b	0

Note: See Appendix 2 for survey questions and answers.
Answer Key included at end of Appendix 6.

Appendix 6 (Continued)

Key for Survey Answers

Occupations
- j) Disabled
- k) Retired
- l) Homemaker
- m) Student
- n) Teacher
- o) Nurse
- p) Administration/Managerial
- q) Professional
- r) Other

Medications
- m) Anti-inflammatory
- n) Migraine
- o) Skin Care
- p) Circulation
- q) Cancer
- r) Pain
- s) Cholesterol
- t) Blood pressure
- u) Osteoporosis/arthritis
- v) Anxiety/depression
- w) Organ rejection
- x) Diabetes

Reasons for Non-Prosthesis Use
- g) Fatigue
- h) Wounds/Sores/Skin Problems
- i) Doesn't Fit/ Bad fit
- j) Pain
- k) Cumbersome
- l) Other

Other Assistive Devices
- f) Cane
- g) Walker
- h) Crutches
- i) Wheelchair
- j) Other

Nature of Back Pain
- h) Piercing
- i) Ache
- j) Throb
- k) Stabbing
- l) Stiffness
- m) Burning
- n) Cramping

Location of Back Pain
- g) Lower back
- h) Neck
- i) Sacroiliac
- j) Mid Back
- k) Between Shoulder Blades
- l) Above Hips

Medical Condition that Causes Back Pain (other than amputation)
- f) Fracture/dislocation/deformation of hip or leg
- g) Diabetes
- h) Car accident
- i) Arthritis
- j) Scoliosis/spondylosis/lordosis

Type of Specialist
- e) Chiropractor
- f) PT/rehab specialist
- g) Acupuncturist
- h) Surgeon

Manufacturer
- n) Hanger
- o) CA Tech
- p) Otto Bock
- q) Flex Foot
- r) West Coast
- s) Ohio Willowood
- t) Ossur
- u) Mauch
- v) Seattle Light
- w) Brownsfield
- x) Elation
- y) Luxon
- z) Endolite

Other Activities
- g) Walking
- h) Pilate's/Yoga
- i) Cycling
- j) Team Sports
- k) Yard/House Work
- l) Other

Appendix 7 Excel Spreadsheet of Survey Results for Amputee Subjects

Subject #	1A	2A	3A	4A
Age	38	32	58	81
Weight (lbs)	145	205	146	125
Height (inches)	66	71	65	71
Gender	m	m	f	m
Occupation	clerk	technician	admin asst	retired
Take medicines?	a	a	b	a
Med 1	zestril	todamax		
Med 2	coomadin	celebrex		
Med 3				
Type of prosthesis	a	a	a	b
Side its on	a	b	b	a
Use any other proshesis	b	a	b	b
Manufacturer		micacorp genisus 2		cleg
Weight of prostheis(lbs)		8.5		
Date of amputation	31229	38047	18172	
Date fitted	38444	38139		
% of time using prosthesis	d	c	d	
Longest time able to use it	e	e	e	
Reason for amputation	a	b	e	
Reason (other)			snake bite	
Activity level before amp	d	d		
Activity level after	c	a		a
Activity level now	d	d	c	b
Days a week for swimming	0	2	0	0
Days a week weight training	3	0	0	0
Days a week running	0	2	0	0
Days a week golf	0	0	0	0
Days a week other activity	3	7	4	0
Other activity	stationary bike	walking		
Satisfaction	b	a	a	a
Satisfaction with life before	a	a		a
Satisfaction with life after	b	a		b
Reason for no use	sleeping	sleep/shower		
Other assist device	b	a	b	b
Assistive device		crutch		

Note: See Appendix 1 for key to survey answers.

Appendix 7 (Continued)

Experience back pain	b	a	a	
Medical condition for back pain	b	b	b	
Medical condition				
Level of back pain	0	2	1	
Location of back pain		lower right	lower back	
Nature of back pain		constricting/cramp	throbbing	
Pain in last 4 weeks	f	a	a	
Pain interfere with a	6	1	1	
Pain interfere with b	6	1	1	
Pain interfere with c	6	2	1	
Pain interfere with d	6	3	1	
Pain interfere with e	6	2	1	
Seeing a specialist for pain	b	b	b	b
Type of specialist				
Experience hip pain	b	a	b	b
Level of hip pain	0	2	0	
Experience phantom pain	b	a	b	a
Level of phantom pain	0	3	0	4
Experience phantom sensation	b	a	a	a
Level of phantom sensation	0	2	1	3
Experience pain in nonamp leg	b	a	b	b

Note: See Appendix 1 for key to survey answers.

Appendix 8 Excel Spreadsheet of Survey Results for Control Subjects

Subject #	1C	2C	3C
Age	20	32	35
Weight (lbs)	168	165	194
Height (inches)	65	68	71
Gender	f	m	m
Occupation	student	student	student
Taking medication	b	b	b
Med 1			
Med2			
Med3			
Activity level	c	b	d
Days a week swim	0	0	0
Days a week weight train	0	2	1
Days a week run	0	0.5	1
Days a week golf	0	0	0
Days a week other activity		1	0
Other activity	walking	tennis	
Satisfaction	b	b	b
Experience back pain	b	b	a
Medical condition for back pain	b	b	a
Type of medical condition			injury
Level of back pain	0	0	5
Location of back pain			lowerback
Nature of back pain			piercing
Frequency of pain in last 4weeks	f	f	f
Pain interfere with a	6	1	4
Pain interfere with b	6	1	3
Pain interfere with c	6	1	2
Pain interfere with d	6	1	5
Pain interfere with e	6	1	5
Seeing a specialist for pain	b	b	b
Type of specialist			
Experience hip pain	b	b	b
Level of hip pain	0	0	0

Note: See Appendix 2 for key to survey answers.

Appendix 9 Excel Spreadsheet of Maximum Acceleration Changes

Subject	N1			N2			N3		
1A	ML	MR	Diff	ML	MR	Diff	ML	MR	Diff
	amp	nonamp		amp	nonamp		amp	nonamp	
	0.45077	1.04587	0.5951	1.31907	0.96297	-0.3561	1.37757	0.77757	-0.6
	1.08977	0.87027	-0.2195	1.70437	1.00197	-0.7024	1.37757	1.08487	-0.2927
	1.37757	1.17267	-0.2049	1.64097	0.98727	-0.6537	1.36777	0.73857	-0.6292
	1.43127	0.99707	-0.4342	1.19707	0.59707	-0.6	1.18727	0.91907	-0.2682
	1.45557	0.88487	-0.5707	1.29467	0.78247	-0.5122	1.14827	0.85557	-0.2927
				1.20687	0.82147	-0.3854	1.51907	0.80687	-0.7122
	nonamp	amp		nonamp	amp		nonamp	amp	
2A	0.40267	0.64167	-0.239	0.49047	0.89047	-0.4	0.30997	0.60267	-0.2927
	0.63677	0.93927	-0.3025	0.41237	0.88067	-0.4683	0.47097	0.83187	-0.3609
	0.58797	0.88557	-0.2976	0.30997	0.64167	-0.3317	0.42707	0.77337	-0.3463
	0.35877	0.54407	-0.1853	0.31487	0.95877	-0.6439	0.27097	0.68067	-0.4097
	0.38317	0.75877	-0.3756	0.34407	0.70507	-0.361	0.28067	0.66117	-0.3805
	nonamp	amp		nonamp	amp		nonamp	amp	
3A	0.38167	0.41577	-0.0341	0.22557	0.23527	-0.0097	0.43527	0.38647	0.0488
	0.47437	0.24017	0.2342	0.30847	0.32797	-0.0195	0.49867	0.33287	0.1658
	0.34257	0.35237	-0.0098	0.31337	0.27437	0.039	0.41087	0.43527	-0.0244
	0.39137	0.32797	0.0634	0.29387	0.28407	0.0098	0.49387	0.34257	0.1513
	0.36697	0.30847	0.0585	0.39137	0.34257	0.0488	0.38647	0.32797	0.0585
	0.39137		0.39137	0.37187	0.27917	0.0927			
1C	0.4645	0.2694	0.1951	0.3279	0.5718	-0.2439	0.5962	0.445	0.1512
	0.4206	0.323	0.0976	0.3328	0.5084	-0.1756	0.5669	0.4157	0.1512
	0.4547	0.2694	0.1853	0.3328	0.4157	-0.0829	0.4742	0.4645	0.0097
	0.4694	0.3133	0.1561	0.3864	0.4791	-0.0927	0.4938	0.4694	0.0244
	0.2499	0.362	-0.1121	0.3328	0.4889	-0.1561	0.4742	0.3767	0.0975
	0.3425	0.1864	0.1561	0.3864	0.5328	-0.1464	0.4108	0.3864	0.0244
	0.2011	0.3035	-0.1024						
2C	0.42964	0.23944	0.1902	0.57114	0.32234	0.2488	0.48334	0.36624	0.1171
	0.54674	0.25894	0.2878	0.39544	0.50764	-0.1122	0.45894	0.27354	0.1854
	0.30284	0.36624	-0.0634	0.41984	0.48814	-0.0683	0.34184	0.29304	0.0488
	0.60524	0.31254	0.2927	0.54184	0.30284	0.239	0.49304	0.35644	0.1366
	0.33694	0.33204	0.0049	0.57114	0.31744	0.2537			
3C	0.41234	0.37324	0.0391	0.40254	0.31964	0.0829	0.37324	0.34404	0.0292
	0.49524	0.31964	0.1756	0.50494	0.33424	0.1707	0.45134	0.55864	-0.1073
	0.55374	0.44154	0.1122	0.47574	0.37324	0.1025	0.36354	0.48064	-0.1171
	0.35374	0.37324	-0.0195	0.51474	0.41234	0.1024	0.38794	0.44154	-0.0536
		0.35864	-0.35864	0.44644	0.41234	0.0341			

Key:
ML = peak acceleration change for the left leg
MR = peak acceleration change for the right leg
Diff = Difference between ML and MR
N1, N2, N3 = normal walking trials 1,2,3
A = amputee
C = Control

Appendix 9 (Continued)

Subject	F1			F2			F3		
1A	ML	MR	Diff	ML	MR	Diff	ML	MR	Diff
	amp	nonamp		amp	nonamp		amp	nonamp	
	1.11417	1.07997	-0.0342	1.42147	0.80687	-0.6146	1.92877	1.15807	-0.7707
	1.93857	1.07027	-0.8683	1.22637	0.91417	-0.3122	1.49467	1.35807	-0.1366
	2.32387	1.04097	-1.2829	1.44097	1.10437	-0.3366	1.33367	1.11907	-0.2146
	1.86537	0.97757	-0.8878	1.06537	0.78727	-0.2781	1.81657	0.80197	-1.0146
	1.93857	0.71417	-1.2244	1.20197	0.85077	-0.3512	0.70927	1.27027	0.561
	2.24097	0.91907	-1.3219	1.58247	1.08977	-0.4927			
	nonamp	amp		nonamp	amp		nonamp	amp	
2A	0.68067	1.19777	-0.5171	0.52457	1.16357	-0.639	0.47577	1.14897	-0.6732
	0.85137	1.55387	-0.7025	0.41237	1.23187	-0.8195	0.38797	1.22707	-0.8391
	0.60747	1.81727	-1.2098	0.38797	0.66557	-0.2776	0.67097	1.07577	-0.4048
	0.85137	1.09537	-0.244	0.37827	0.79287	-0.4146	0.42707	1.12457	-0.6975
				0.42707				1.77337	-1.77337
	nonamp	amp		nonamp	amp		nonamp	amp	
3A	0.54747	0.65967	-0.1122	0.21577	0.42557	-0.2098	0.31827	0.58167	-0.2634
	0.53287	0.43527	0.0976	0.47917	0.47917	0	0.50847	0.52307	-0.0146
	0.68897	0.49867	0.1903	0.51337	0.63047	-0.1171	0.43527	0.61087	-0.1756
	0.56217	0.46457	0.0976	0.55727	0.55237	0.0049	0.58167	0.62067	-0.039
	0.59627		0.59627	0.46457	0.52307	-0.0585	0.43047	0.42067	0.0098
1C	0.3425	0.4401	-0.0976	0.5133	0.5425	-0.0292	0.5767	0.3767	0.2
	0.4596	0.3816	0.078	0.5425	0.5962	-0.0537	0.4547	0.5035	-0.0488
	0.7718	0.7718	0	0.4547	0.5718	-0.1171	0.6547	0.4401	0.2146
	0.6694	0.5279	0.1415	0.562	0.8059	-0.2439	0.6401	0.762	-0.1219
	0.484	0.6157	-0.1317	0.7523	0.8694	-0.1171	0.4499	0.5328	-0.0829
	0.5913		0.5913						
2C	1.00034	0.95644	0.0439	1.40524	1.09794	0.3073	0.86864	1.07844	-0.2098
	0.79544	1.17594	-0.3805	1.13694	0.83454	0.3024	1.09304	1.07354	0.0195
	0.68334	0.88814	-0.2048	0.92724	0.72234	0.2049	0.74184	0.68814	0.0537
				0.67354		0.67354	0.68334	0.55644	0.1269
3C	0.93424	0.86104	0.0732	1.12454	1.18794	-0.0634	1.24154	0.78304	0.4585
	1.17324	1.71474	-0.5415	1.32934	1.13914	0.1902	1.31964	1.63674	-0.3171
	1.50494	1.34884	0.1561	1.48064	1.17324	0.3074	1.32934	1.29034	0.039
		1.81714	-1.81714		1.54884	-1.54884	1.34884	1.48064	-0.1318
								1.60744	-1.60744

Key:
ML = peak acceleration change for the left leg
MR = peak acceleration change for the right leg
Diff = Difference between ML and MR
F1, F2, F3 = Fast walking trials 1,2,3
A = amputee
C = Control

Appendix 9 (Continued)

Subject	S1			S2			S3		
1A	ML	MR	Diff	ML	MR	Diff	ML	MR	Diff
	amp	nonamp		amp	nonamp		amp	nonamp	
	0.34337	0.21657	-0.1268	0.28487	0.31417	0.0293	0.29947	0.28487	-0.0146
	0.17757	0.27027	0.0927	0.44097	0.44097	0	0.30437	0.28977	-0.0146
	0.19707	0.23607	0.039	0.30437	0.37757	0.0732	0.21657	0.24587	0.0293
	0.25077	0.33367	0.0829	0.32877	0.29947	-0.0293	0.33857	0.25077	-0.0878
	0.13367	0.26047	0.1268	0.25557	0.25077	-0.0048	0.29467	0.35807	0.0634
	0.14827	0.29947	0.1512	0.40197	0.38727	-0.0147	0.41167	0.32877	-0.0829
		0.24587	0.24587	0.32387	0.29947	-0.0244	0.47997	0.28487	-0.1951
				0.31907		-0.31907	0.32877		-0.32877
2A	nonamp	amp		nonamp	amp		nonamp	amp	
	0.33437	0.39287	-0.0585	0.32457	0.80747	-0.4829	0.24167	0.63187	-0.3902
	0.27097	0.74897	-0.478	0.19287	0.78797	-0.5951	0.24657	0.74897	-0.5024
	0.34407	0.60267	-0.2586	0.30017	0.80747	-0.5073	0.24657	0.53927	-0.2927
	0.27577	0.60267	-0.3269	0.29047	0.70507	-0.4146	0.23187	0.60267	-0.3708
	0.53437	0.50507	0.0293	0.23677	0.90997	-0.6732	0.19287	0.66117	-0.4683
	0.36357		0.36357		0.80747	-0.80747			0
3A	nonamp	amp		nonamp	amp		nonamp	amp	
	0.20607	0.39627	-0.1902	0.33777	0.42067	-0.0829	0.26457	0.35237	-0.0878
	0.26947	0.28897	-0.0195	0.23047	0.24997	-0.0195	0.29867	0.28407	0.0146
	0.24017	0.33777	-0.0976	0.26457	0.22557	0.039	0.24997	0.31337	-0.0634
	0.23527	0.31337	-0.0781	0.27917	0.21697	0.0622	0.31337	0.32797	-0.0146
	0.30357	0.39627	-0.0927	0.35237	0.30357	0.0488	0.26947	0.30357	-0.0341
	0.12307	0.37187	-0.2488	0.16697		0.16697		0.30357	-0.30357
1C	0.2791	0.1474	0.1317	0.2791	0.4255	-0.1464	0.4499	0.3767	0.0732
	0.284	0.2108	0.0732	0.3425	0.2791	0.0634	0.5767	0.3718	0.2049
	0.2206	0.3084	-0.0878	0.4303	0.284	0.1463	0.3377	0.4157	-0.078
	0.2157	0.2694	-0.0537	0.3328	0.1816	0.1512	0.3035	0.3377	-0.0342
	0.2108	0.3377	-0.1269	0.2742	0.4011	-0.1269	0.2742	0.3328	-0.0586
	0.323	0.3523	-0.0293	0.2742	0.3035	-0.0293	0.3181	0.4986	-0.1805
	0.323	0.3572	-0.0342	0.4352		0.4352			
2C	0.49304	0.32234	0.1707	0.55644	0.38084	0.1756	0.29794	0.28334	0.0146
	0.37594	0.41504	-0.0391	0.42964	0.35644	0.0732	0.36624	0.35154	0.0147
	0.41014	0.41014	0	0.67844	0.32724	0.3512	0.51744	0.32234	0.1951
	0.39064	0.30284	0.0878	0.49304	0.39064	0.1024	0.46374	0.34184	0.1219
	0.42964		0.42964		0.30284	-0.30284	0.44914		
3C	0.32934	0.16844	0.1609	0.34404	0.25624	0.0878	0.25624	0.33424	-0.078
	0.27084	0.17324	0.0976	0.48064	0.32934	0.1513	0.21234	0.32454	-0.1122
	0.50984	0.30494	0.2049	0.37324	0.29034	0.0829	0.17814	0.43674	-0.2586
	0.46104	0.46594	-0.0049	0.33914	0.19764	0.1415	0.18304	0.35864	-0.1756
	0.31964	0.31474	0.0049	0.36844	0.33914	0.0293	0.24644	0.44644	-0.2
	0.35374	0.20744	0.1463	0.38794	0.27084	0.1171	0.19274	0.39274	-0.2
	0.44154	0.22204	0.2195	0.31964	0.23184	0.0878			

Appendix 9 (Continued)

Subject	½ inch Right Leg On			1 inch Right Leg On		
1A	ML	MR	Diff	ML	MR	Diff
	amp	nonamp		amp	nonamp	
	1.02637	0.73857	-0.2878	0.89467	0.95317	0.0585
	1.48977	1.06537	-0.4244	1.31907	1.00197	-0.3171
	0.92877	1.17757	0.2488	1.18247	1.09467	-0.0878
	0.61657	1.38727	0.7707			
2A	nonamp	amp		nonamp	amp	
	0.27097	0.91967	-0.6487	0.32457	1.35877	-1.0342
	0.22707	1.08557	-0.8585	0.15877	1.36847	-1.2097
	0.22707	0.54407	-0.317	0.31487	1.90507	-1.5902
		0.59287	-0.59287		0.75877	-0.75877
3A	nonamp	amp		nonamp	amp	
	0.24017	0.17677	0.0634	0.29867	0.24997	0.0487
	0.24507	0.25477	-0.0097	0.49387	0.34257	0.1513
	0.34257	0.24507	0.0975	0.38647	0.36217	0.0243
	0.32797	0.26457	0.0634	0.35237	0.35727	-0.0049
		0.20607	-0.20607		0.45477	-0.45477
1C	0.1133	0.284	-0.1707	0.2059	0.4645	-0.2586
	0.2547	0.5035	-0.2488	0.284	0.5084	-0.2244
	0.2645	0.3328	-0.0683	0.2401	0.5669	-0.3268
	0.2499	0.3425	-0.0926	0.1816	0.3377	-0.1561
				0.1669		0.1669
2C	0.30284	0.46864	-0.1658	0.35154	0.15154	0.2
	0.30764	0.46864	-0.161	0.37114	0.60524	-0.2341
	0.40034	0.67354	-0.2732	0.41984	0.66374	-0.2439
		0.52234	-0.52234			
3C	0.29524	0.10494	0.1903	0.10494	0.35374	-0.2488
	0.60744	0.31474	0.2927	0.27574	0.47574	-0.2
	0.48064	0.23674	0.2439	0.42204	0.29524	0.1268
	0.56354	0.54404	0.0195	0.46104	0.28544	0.1756
	0.50494	0.35374	0.1512	0.39764	0.39274	0.0049
				0.39274		0.39274

Key:
ML = peak acceleration change for the left leg
MR = peak acceleration change for the right leg
Diff = Difference between ML and MR

A = Amputee
C = Control

Appendix 9 (Continued)

Subject	½ inch Left Leg On			1 inch Left Leg On		
1A	ML	MR		ML	MR	
	amp	nonamp		amp	nonamp	
	0.56777	1.01167	0.4439	0.71417	0.64587	-0.0683
	1.05077	1.23127	0.1805	0.96297	1.27027	0.3073
	0.69467	0.93367	0.239	0.64097	1.29467	0.6537
	1.15807		-1.15807	1.38727	0.51907	-0.8682
2A	nonamp	amp		nonamp	amp	
	0.48557	0.23187	0.2537			
	0.50507	0.55387	-0.0488			
	1.00747	0.21237	0.7951			
3A	nonamp	amp		nonamp	amp	
	0.31337	0.34747	-0.0341	0.34747	0.28407	0.0634
	0.42067	0.26947	0.1512	0.39627	0.30847	0.0878
	0.33777	0.29867	0.0391	0.56217	0.33287	0.2293
	0.31337	0.33777	-0.0244		0.52307	-0.52307

Key:
ML = peak acceleration change for the left leg
MR = peak acceleration change for the right leg
Diff = Difference between ML and MR
A = Amputee
C = Control

Appendix 10 Excel Spreadsheet of Means and Standard Deviations

Normal	1A N		2A N		3A N	
Trials	Amp	NonAmp	Amp	NonAmp	Amp	NonAmp
For	0.45077	1.04587	0.64167	0.40267	0.41577	0.38167
Amputees	1.08977	0.87027	0.93927	0.63677	0.24017	0.47437
	1.37757	1.17267	0.88557	0.58797	0.35237	0.34257
	1.43127	0.99707	0.54407	0.35877	0.32797	0.39137
	1.45557	0.88487	0.75877	0.38317	0.30847	0.36697
	1.31907	0.96297	0.89047	0.49047	0.23527	0.39137
	1.70437	1.00197	0.88067	0.41237	0.32797	0.22557
	1.64097	0.98727	0.64167	0.30997	0.27437	0.30847
	1.19707	0.59707	0.95877	0.31487	0.28407	0.31337
	1.29467	0.78247	0.70507	0.34407	0.34257	0.29387
	1.20687	0.82147	0.60267	0.30997	0.27917	0.39137
	1.37757	0.77757	0.83187	0.47097	0.38647	0.37187
	1.37757	1.08487	0.77337	0.42707	0.33287	0.43527
	1.36777	0.73857	0.68067	0.27097	0.43527	0.49867
	1.18727	0.91907	0.66117	0.28067	0.34257	0.41087
	1.14827	0.85557			0.32797	0.49387
	1.51907	0.80687				0.38647
Mean	1.302676	0.900382	0.759717	0.40005	0.325833	0.381058
Std Dev	0.275284	0.142768	0.131693	0.10855	0.056262	0.071953

Average of the Averages						
	Amputess	amp	nonamp		Difference	
	avg	0.796075	0.560497		0.235578	0.166579
	std dev	0.489436	0.294502			

Appendix 10 (Continued)

Normal Trials For Controls	1C N Left	Right	2C N Left	Right	3C N Left	Right
	0.4645	0.2694	0.42964	0.23944	0.41234	0.37324
	0.4206	0.323	0.54674	0.25894	0.49524	0.31964
	0.4547	0.2694	0.30284	0.36624	0.55374	0.44154
	0.4694	0.3133	0.60524	0.31254	0.35374	0.37324
	0.2499	0.362	0.33694	0.33204	0.40254	0.35864
	0.3425	0.1864	0.57114	0.32234	0.50494	0.31964
	0.2011	0.3035	0.39544	0.50764	0.47574	0.33424
	0.3279	0.5718	0.41984	0.48814	0.51474	0.37324
	0.3328	0.5084	0.54184	0.30284	0.44644	0.41234
	0.3328	0.4157	0.57114	0.31744	0.37324	0.41234
	0.3864	0.4791	0.48334	0.36624	0.45134	0.34404
	0.3328	0.4889	0.45894	0.27354	0.36354	0.55864
	0.3864	0.5328	0.34184	0.29304	0.38794	0.48064
	0.5962	0.445	0.49304	0.35644		0.44154
	0.5669	0.4157				
	0.4742	0.4645				
	0.4938	0.4694				
	0.4742	0.3767				
	0.4108	0.3864				
Mean	0.406205	0.399021	0.46414	0.338347	0.441194	0.395926
Std Dev	0.100679	0.102525	0.096845	0.077451	0.064448	0.067609

Average	Of The	Averages	
	Controls	left	right
	avg	0.43718	0.377765
	std dev	0.029175	0.034172

Appendix 10 (Continued)

Fast Trials For Amputees	1A Amp	1A NonAmp	2A Amp	2A NonAmp	3A Amp	3A NonAmp
	1.11417	1.07997	1.19777	0.68067	0.65967	0.54747
	1.93857	1.07027	1.55387	0.85137	0.43527	0.53287
	2.32387	1.04097	1.81727	0.60747	0.49867	0.68897
	1.86537	0.97757	1.09537	0.85137	0.46457	0.56217
	1.93857	0.71417	1.16357	0.52457	0.42557	0.59627
	2.24097	0.91907	1.23187	0.41237	0.47917	0.21577
	1.42147	0.80687	0.66557	0.38797	0.63047	0.47917
	1.22637	0.91417	0.79287	0.37827	0.55237	0.51337
	1.44097	1.10437	1.14897	0.42707	0.52307	0.55727
	1.06537	0.78727	1.22707	0.47577	0.58167	0.46457
	1.20197	0.85077	1.07577	0.38797	0.52307	0.31827
	1.58247	1.08977	1.12457	0.67097	0.61087	0.50847
	1.92877	1.15807	1.77337	0.42707	0.62067	0.43527
	1.49467	1.35807			0.42067	0.58167
	1.33367	1.11907				0.43047
	1.81657	0.80197				
	0.70927	1.27027				
Mean	1.567241	1.003688	1.220608	0.544839	0.530413	0.49547
Std Dev	0.441874	0.17894	0.331487	0.171667	0.080676	0.115448

Average of the Averages

Amputess amp		nonamp	Difference	
Avg	1.106087	0.681332	0.424755	0.300347
Std dev	0.527816	0.280257		

Appendix 10 (Continued)

Fast Trials For Controls	1C Left	Right	2C Left	Right	3C Left	Right
	0.3425	0.4401	1.00034	0.95644	0.93424	0.86104
	0.4596	0.3816	0.79544	1.17594	1.17324	1.71474
	0.7718	0.7718	0.68334	0.88814	1.50494	1.34884
	0.6694	0.5279	1.40524	1.09794	1.12454	1.81714
	0.484	0.6157	1.13694	0.83454	1.32934	1.18794
	0.5913	0.5425	0.92724	0.72234	1.48064	1.13914
	0.5133	0.5962	0.67354	1.07844	1.24154	1.17324
	0.5425	0.5718	0.86864	1.07354	1.31964	1.54884
	0.4547	0.8059	1.09304	0.68814	1.32934	0.78304
	0.562	0.8694	0.74184	0.55644	1.34884	1.63674
	0.7523	0.3767	0.68334			1.29034
	0.5767	0.5035				1.48064
	0.4547	0.4401				1.60744
	0.6547	0.762				
	0.6401	0.5328				
	0.4499					
Mean	0.557469	0.582533	0.909904	0.90719	1.27863	1.353009
Std Dev	0.118406	0.155435	0.232487	0.205171	0.169512	0.319152

Average of the Averages

Controls	left	right		Difference	
Avg	0.915334	0.947578		-0.03224	0.0228
Std Dev	0.360611	0.386822			

Appendix 10 (Continued)

Slow Trials For Amputees	1A Amp	1A NonAmp	2A Amp	2A NonAmp	3A Amp	3A NonAmp
	0.34337	0.21657	0.39287	0.33437	0.39627	0.20607
	0.17757	0.27027	0.74897	0.27097	0.28897	0.26947
	0.19707	0.23607	0.60267	0.34407	0.33777	0.24017
	0.25077	0.33367	0.60267	0.27577	0.31337	0.23527
	0.13367	0.26047	0.50507	0.53437	0.39627	0.30357
	0.14827	0.29947	0.80747	0.36357	0.37187	0.12307
	0.28487	0.24587	0.78797	0.32457	0.42067	0.33777
	0.44097	0.31417	0.80747	0.19287	0.24997	0.23047
	0.30437	0.44097	0.70507	0.30017	0.22557	0.26457
	0.32877	0.37757	0.90997	0.29047	0.21697	0.27917
	0.25557	0.29947	0.80747	0.23677	0.30357	0.35237
	0.40197	0.25077	0.63187	0.24167	0.35237	0.16697
	0.32387	0.38727	0.74897	0.24657	0.28407	0.26457
	0.31907	0.29947	0.53927	0.24657	0.31337	0.29867
	0.29947	0.28487	0.60267	0.23187	0.32797	0.24997
	0.30437	0.28977	0.66117	0.19287	0.30357	0.31337
	0.21657	0.24587			0.30357	0.26947
	0.33857	0.25077				
	0.29467	0.35807				
	0.41167	0.32877				
	0.47997	0.28487				
	0.32877					
Mean	0.299284	0.298813	0.678851	0.28922	0.318011	0.259117
Std Dev	0.089709	0.056469	0.13586	0.082891	0.057775	0.057927

Average of the Averages

Amputees	amp	nonamp	difference
avg	0.432049	0.282383	0.149665
std dev	0.213942	0.020712	0.105829

Appendix 10 (Continued)

Slow						
Trials	1C		2C		3C	
For	Left	Right	Left	Right	Left	Right
Controls	0.2791	0.1474	0.49304	0.32234	0.32934	0.16844
	0.284	0.2108	0.37594	0.41504	0.27084	0.17324
	0.2206	0.3084	0.41014	0.41014	0.50984	0.30494
	0.2157	0.2694	0.39064	0.30284	0.46104	0.46594
	0.2108	0.3377	0.42964	0.38084	0.31964	0.31474
	0.323	0.3523	0.55644	0.35644	0.35374	0.20744
	0.323	0.3572	0.42964	0.32724	0.44154	0.22204
	0.2791	0.4255	0.67844	0.39064	0.34404	0.25624
	0.3425	0.2791	0.49304	0.30284	0.48064	0.32934
	0.4303	0.284	0.29794	0.28334	0.37324	0.29034
	0.3328	0.1816	0.36624	0.35154	0.33914	0.19764
	0.2742	0.4011	0.51744	0.32234	0.36844	0.33914
	0.2742	0.3035	0.46374	0.34184	0.38794	0.27084
	0.4352	0.3767	0.44914		0.31964	0.23184
	0.4499	0.3718			0.25624	0.33424
	0.5767	0.4157			0.21234	0.32454
	0.3377	0.3377			0.17814	0.43674
	0.3035	0.3328			0.18304	0.35864
	0.2742	0.4986			0.24644	0.44644
	0.3181				0.19274	0.39274
Mean	0.32423	0.325858	0.453676	0.346725	0.3284	0.303275
Std Dev	0.089661	0.086292	0.093369	0.042191	0.098842	0.088827

Average of the Averages

controls	left	right		Difference
Avg	0.368769	0.325286		0.043483
std dev	0.073561	0.02173		0.030747

Appendix 10 (Continued)

1/2 inch long

Amputees	1A		2A		3A	
	Amp	NonAmp	Amp	NonAmp	Amp	NonAmp
	1.02637	0.73857	0.91967	0.27097	0.17677	0.24017
	1.48977	1.06537	1.08557	0.22707	0.25477	0.24507
	0.92877	1.17757	0.54407	0.22707	0.24507	0.34257
	0.61657	1.38727	0.59287		0.26457	0.32797
					0.20607	
Mean	1.01537	1.092195	0.785545	0.241703	0.22945	0.288945
std dev	0.361348	0.27088	0.260409	0.025346	0.039821	0.05386

Controls	1C		2C		3C	
	Left	Right	Left	Right	Left	Right
	0.1133	0.284	0.30284	0.46864	0.29524	0.10494
	0.2547	0.5035	0.30764	0.46864	0.60744	0.31474
	0.2645	0.3328	0.40034	0.67354	0.48064	0.23674
	0.2499	0.3425		0.52234	0.56354	0.54404
					0.50494	0.35374
Mean	0.2206	0.3657	0.33694	0.53329	0.49036	0.31084
Std dev	0.071791	0.095367	0.054958	0.096866	0.138053	0.184231

Average of the Averages

Amputess	amp	nonamp		Difference	
avg	0.676788	0.540948		0.135841	0.096054
std dev	0.40409	0.477978			
Controls	left	right		Difference	
avg	0.3493	0.403277		-0.05398	0.038167
std dev	0.135304	0.115888			

1 inch long

Amputees	1A		2A		3A	
	Amp	NonAmp	Amp	NonAmp	Amp	NonAmp
	0.89467	0.95317	1.35877	0.32457	0.24997	0.29867
	1.31907	1.00197	1.36847	0.15877	0.34257	0.49387
	1.18247	1.09467	1.90507	0.31487	0.36217	0.38647
			0.75877		0.35727	0.35237
					0.45477	
mean	1.13207	1.016603	1.34777	0.26607	0.35335	0.382845
std dev	0.216642	0.071876	0.46835	0.093051	0.072772	0.082369

Controls	1C		2C		3C	
	Left	Right	Left	Right	Left	Right
	0.2059	0.4645	0.35154	0.15154	0.10494	0.35374
	0.284	0.5084	0.37114	0.60524	0.27574	0.47574
	0.2401	0.5669	0.41984	0.66374	0.42204	0.29524
	0.1816	0.3377			0.46104	0.28544
	0.1669				0.39764	0.39274
					0.39274	
Mean	0.2279	0.469375	0.38084	0.473507	0.33228	0.36058
std dev	0.047171	0.09729	0.035168	0.280361	0.131783	0.077875

Average of the Averages

Amputess	amp	nonamp		difference	
avg	0.944397	0.555173		0.389224	0.275223
std dev	0.5231	0.403854			
Controls	left	right		difference	
avg	0.313673	0.434487		-0.12081	0.085428
std dev	0.078149	0.064039			

Appendix 10 (Continued)

1/2 inch short

Amputees	1A		2A		3A	
	Amp	NonAmp	Amp	NonAmp	Amp	NonAmp
	0.56777	1.01167	0.23187	0.48557	0.34747	0.31337
	1.05077	1.23127	0.55387	0.50507	0.26947	0.42067
	0.69467	0.93367	0.21237	1.00747	0.29867	0.33777
	1.15807				0.33777	0.31337
mean	0.86782	1.05887	0.332703	0.666037	0.313345	0.346295
std dev	0.2815	0.154312	0.191784	0.295851	0.036062	0.0509

Average of the Averages

Amputess	amp	nonamp		Difference	
avg	0.504623	0.690401		-0.18578	0.131365
std dev	0.314687	0.356912			

1 inch short

Amputees	1A		2A		3A	
	Amp	NonAmp	Amp	NonAmp	Amp	NonAmp
	0.71417	0.64587			0.28407	0.34747
	0.96297	1.27027			0.30847	0.39627
	0.64097	1.29467			0.33287	0.56217
	1.38727	0.51907			0.52307	
mean	0.926345	0.93247			0.36212	0.435303
std dev	0.336774	0.407569			0.109134	0.112547

Average of the Averages

Amputess	amp	nonamp		Difference	
avg	0.644233	0.683887		-0.03965	0.02804
std dev	0.398967	0.35155			

Appendix 11 Excel Spreadsheet of Delta Values

Delta Values: Normal Trials	1A	2A	3A	1C	2C	3C
	0.5951	-0.239	-0.0341	0.1951	0.1902	0.0391
	-0.2195	-0.3025	0.2342	0.0976	0.2878	0.1756
	-0.2049	-0.2976	-0.0098	0.1853	-0.0634	0.1122
	-0.4342	-0.1853	0.0634	0.1561	0.2927	-0.0195
	-0.5707	-0.3756	0.0585	-0.1121	0.0049	-0.35864
	-0.3561	-0.4	0.39137	0.1561	0.2488	0.0829
	-0.7024	-0.4683	-0.0097	-0.1024	-0.1122	0.1707
	-0.6537	-0.3317	-0.0195	-0.2439	-0.0683	0.1025
	-0.6	-0.6439	0.039	-0.1756	0.239	0.1024
	-0.5122	-0.361	0.0098	-0.0829	0.2537	0.0341
	-0.3854	-0.2927	0.0488	-0.0927	0.1171	0.0292
	-0.6	-0.3609	0.0927	-0.1561	0.1854	-0.1073
	-0.2927	-0.3463	0.0488	-0.1464	0.0488	-0.1171
	-0.6292	-0.4097	0.1658	0.1512	0.1366	-0.0536
	-0.2682	-0.3805	-0.0244	0.1512		
	-0.2927		0.1513	0.0097		
	-0.7122		0.0585	0.0244		
				0.0975		
				0.0244		
Mean	-0.40229	-0.35967	0.074392	0.007184	0.125793	0.013754
Std Dev	0.309437	0.105201	0.109683	0.141585	0.140591	0.140992
Neg	16	15	5	8	3	5
Pos	1	0	12	1	11	9
%Neg	94.11765	100	29.41176	42.10526	21.42857	35.71429

Appendix 11 (Continued)

Delta Values: Fast Trials	1A	2A	3A	1C	2C	3C
	-0.0342	-0.5171	-0.1122	-0.0976	0.0439	0.0732
	-0.8683	-0.7025	0.0976	0.078	-0.3805	-0.5415
	-1.2829	-1.2098	0.1903	0	-0.2048	0.1561
	-0.8878	-0.244	0.0976	0.1415	0.3073	-1.81714
	-1.2244	-0.639	0.59627	-0.1317	0.3024	-0.0634
	-1.3219	-0.8195	-0.2098	0.5913	0.2049	0.1902
	-0.6146	-0.2776	0	-0.0292	0.67354	0.3074
	-0.3122	-0.4146	-0.1171	-0.0537	-0.2098	-1.54884
	-0.3366	-0.6732	0.0049	-0.1171	0.0195	0.4585
	-0.2781	-0.8391	-0.0585	-0.2439	0.0537	-0.3171
	-0.3512	-0.4048	-0.2634	-0.1171	0.1269	0.039
	-0.4927	-0.6975	-0.0146	0.2		-0.1318
	-0.7707	-1.77337	-0.1756	-0.0488		-1.60744
	-0.1366		-0.039	0.2146		
	-0.2146		0.0098	-0.1219		
	-1.0146			-0.0829		
	0.561					
Mean	-0.56355	-0.70862	0.000418	0.011344	0.085185	-0.36945
Std Dev	0.504443	0.412062	0.204697	0.200028	0.292187	0.779833
Neg	16	13	8	10	3	7
Pos	1	0	7	6	8	6
% Neg	94.11765	100	53.33333	62.5	27.27273	53.84615

Appendix 11 (Continued)

Delta Values: Slow Trials	1A	2A	3A	1C	2C	3C
	-0.1268	-0.0585	-0.1902	0.1317	0.1707	0.1609
	0.0927	-0.478	-0.0195	0.0732	-0.0391	0.0976
	0.039	-0.2586	-0.0976	-0.0878	0	0.2049
	0.0829	-0.3269	-0.0781	-0.0537	0.0878	-0.0049
	0.1268	0.0293	-0.0927	-0.1269	0.42964	0.0049
	0.1512	0.36357	-0.2488	-0.0293	0.1756	0.1463
	0.24587	-0.4829	-0.0829	-0.0342	0.0732	0.2195
	0.0293	-0.5951	-0.0195	-0.1464	0.3512	0.0878
	0	-0.5073	0.039	0.0634	0.1024	0.1513
	0.0732	-0.4146	0.0622	0.1463	-0.30284	0.0829
	-0.0293	-0.6732	0.0488	0.1512	0.0146	0.1415
	-0.0048	-0.80747	0.16697	-0.1269	0.0147	0.0293
	-0.0147	-0.3902	-0.0878	-0.0293	0.1951	0.1171
	-0.0244	-0.5024	0.0146	0.4352	0.1219	0.0878
	-0.31907	-0.2927	-0.0634	0.0732		-0.078
	-0.0146	-0.3708	-0.0146	0.2049		-0.1122
	-0.0146	-0.4683	-0.0341	-0.078		-0.2586
	0.0293		-0.30357	-0.0342		-0.1756
	-0.0878			-0.0586		-0.2
	0.0634			-0.1805		-0.2
	-0.0829					
	-0.1951					
	-0.32877					
Mean	-0.01344	-0.36671	-0.05562	0.014665	0.099636	0.025125
Std Dev	0.135522	0.276303	0.112554	0.14758	0.175208	0.146998
Neg	12	15	13	12	2	7
Pos	11	2	5	8	12	13
% Neg	52.17391	88.23529	72.22222	60	14.28571	35

Appendix 11 (Continued)

Delta Values: ½ inch Long	1A	2A	3A	1C	2C	3C
	-0.2878	-0.6487	0.0634	-0.1707	-0.1658	0.1903
	-0.4244	-0.8585	-0.0097	-0.2488	-0.161	0.2927
	0.2488	-0.317	0.0975	-0.0683	-0.2732	0.2439
	0.7707	-0.59287	0.0634	-0.0926	-0.52234	0.0195
			-0.20607			0.1512
Mean	0.076825	-0.60427	0.001706	-0.1451	-0.28059	0.17952
Std Dev	0.546265	0.223055	0.122566	0.081779	0.169289	0.104258
Neg	2	4	2	4	4	0
Pos	2	0	3	0	0	5
%Neg	50	100	40	100	100	0
Delta Values: 1 inch Long						
	0.0585	-1.0342	0.0487	-0.2586	0.2	-0.2488
	-0.3171	-1.2097	0.1513	-0.2244	-0.2341	-0.2
	-0.0878	-1.5902	0.0243	-0.3268	-0.2439	0.1268
		-0.75877	-0.0049	-0.1561		0.1756
			-0.45477	0.1669		0.0049
						0.39274
Mean	-0.11547	-1.14822	-0.04707	-0.1598	-0.09267	0.041873
Std Dev	0.189322	0.348233	0.235379	0.192724	0.253504	0.241894
Neg	2	4	2	4	2	2
Pos	1	0	3	1	1	4
% Neg	66.66667	100	40	80	66.66667	33.33333

Appendix 11 (Continued)

Delta Values: ½ inch short	1A	2A	3A
	0.4439	0.2537	-0.0341
	0.1805	-0.0488	0.1512
	0.239	0.7951	0.0391
	-1.15807		-0.0244
Mean	-0.07367	0.333333	0.03295
Std Dev	0.731703	0.427549	0.085256
Neg	1	1	2
Pos	3	2	2
% Neg	25	33.33333	50
Delta Values: 1 inch Short			
	-0.0683		0.0634
	0.3073		0.0878
	0.6537		0.2293
	-0.8682		-0.52307
Mean	0.006125		-0.03564
Std Dev	0.653208		0.33308
Neg	2		1
Pos	2		3
% Neg	50		25