GAIT ANALYSIS TECHNIQUES TO UNDERSTAND THE EFFECT OF A HIP STRENGTH IMPROVING PROGRAM ON LOWER-LIMB AMPUTEES

BY

EMILY ANNE MORRIS

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Mechanical Engineering
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2011

Urbana, Illinois

Adviser:

Professor Elizabeth Hsiao-Wecksler

ABSTRACT

The ability to walk can be severely compromised by a lower-limb amputation, which can have long-reaching consequences to the individual's health and safety. It has been reported that the high incidence of lower back pain and joint degradation experienced by lower-limb amputees can be attributed to the way amputees carry themselves during walking. The techniques adopted by amputees have a direct correlation to the muscle strength of the residual limb. It was theorized in this study that a hip strength training program would improve amputees' gait performance. An additional aim of the study was to determine if the training program was sufficient to enable lower-limb amputees to run. To assess potential changes in walking gait biomechanics as a consequence of the hip strengthening training, kinematic movement data collected with computerized motion capture techniques were analyzed using both novel and traditional gait analysis methods. A novel technique of time warping gait data to kinematic gait events was developed and validated initially using data from healthy adult males with a simulated knee injury. This technique provided additional insights into temporal shifts in gait behaviors under the simulated injury, as well as providing greater alignment of the kinematic curves. This tool along with standard spatiotemporal metrics and kinematic profile analysis were used to analyze the results from the hip strengthening study. Another analysis of the hip strengthening program data found that the metabolic cost of walking in the training group decreased, hip flexor and extensor strength increased, and all but one member of the training group were able to run after training. In the current study, however, no significant changes in the kinematic gait behaviors for the training group in the pre- vs. post- training analysis were found. The control group's kinematic profiles did show some significant changes after the ten-week period, indicative of deterioration in gait performance. These results suggest that the hip strengthening program may have prevented similar trends from occurring in the training group. The gait analysis tools employed on this data set provided greater insight into the kinematic strategies employed by lower-limb amputees, as well as emphasizing the necessity for continuous muscle strength training in this population.

I dedicate this work to my family.
I can honestly say that without your support,
I wouldn't have gotten this far.

ACKNOWLEDGEMENTS

Quite simply, there are too many people I would like to thank for their guidance, moral support, and friendship along the course of my graduate studies, but I will name a few. First, I would like to thank my adviser, Elizabeth Hsiao-Wecksler, for reading the numerous revisions and helped make sense out of the chaos. I would also like to thank my lab mates for their guidance, advice, and humor. You guys made the experience even more enriching than it would have been otherwise. Finally, I would like to thank my family and close friends for believing in me and providing me with their continuous support. I will always appreciate all you have done for me.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1: INTRODUCTION

Locomotion is a fundamental element of everyday life. Gait can be defined as a cyclic event, which simultaneously propels the body forward and maintains stance stability. As an individual advances, one limb provides a base of support, while the other limb is shifted forward to create a new base [1]. This ability can be severely impacted by a lower-limb amputation, stroke, or other physical impairment causing weakness or loss of function, and can have long-reaching consequences to the individual's health and safety.

In the United States alone, there are an estimated 159,000 people per year who undergo a lower-limb amputation [2]. There are currently 1.6 million people living in the United States with the loss of a lower limb, and this number is expected to double by the year 2050 [3]. There are many forms of lower-limb amputations (e.g. knee, ankle disarticulation, partial foot amputation), but the two major forms this thesis addresses are unilateral (one sided) transtibial (TT, below-knee) and transfemoral (TF, above-knee) amputations. It has been well-documented that individuals with lower-limb amputations have a higher incidence of lower-back and hip and/or knee joint pain, and it has been hypothesized that this pain can be attributed to the way amputees carry themselves during walking [4, 5]. The techniques adopted by amputees can be linked to their residual limb's muscle strength, and it has been shown that muscle strength in the residual limb decreases over time [6]. In order to prevent muscle atrophy in amputees, it is recommended to implement training programs focused on strengthening the muscles of the residual limb [7]. By understanding the mechanisms behind lower-limb amputee gait, it may be possible to develop a training protocol that will not only strengthen the muscles of the thigh, but also to reduce the metabolic cost associated with amputee gait.

1.1. UNDERSTANDING GAIT

Gait can be broken down into a repetitive series of patterns, each representing distinct functional tasks. There are eight of these sub-phases of gait: 1) initial contact, 2) loading response, 3) mid stance, 4) terminal stance, 5) pre-swing, 6) initial swing, 7) mid-swing, and 8) terminal swing [1]. Sub-phases (1) and (2) are involved in weight acceptance, which involves shock absorption, initial limb stability, and the preservation of progression. Sub-phases (3) and (4) make up the single limb support section of gait. During single-limb support, one limb entirely supports the weight of the body in both the sagittal (side) and coronal (frontal) planes. Limb advancement contains sub-phases (5)-(8), and involves the preparatory posturing of the support limb, as well as movement of the limb itself. Knowing the functional requirements of normal gait allows for greater insight into the changes incurred by pathological or injured gait.

Analyzing human gait can be done in a variety of ways, but one of the most common methods is through analyzing temporal and spatial gait parameters, which can provide timing and position information about an individual's gait patterns. A stride consists of one heel strike to the consecutive heel strike by the same foot, while a step is recognized as being the interval between sequential heel strikes by the ipsilateral and contralateral feet (Fig 1.1).

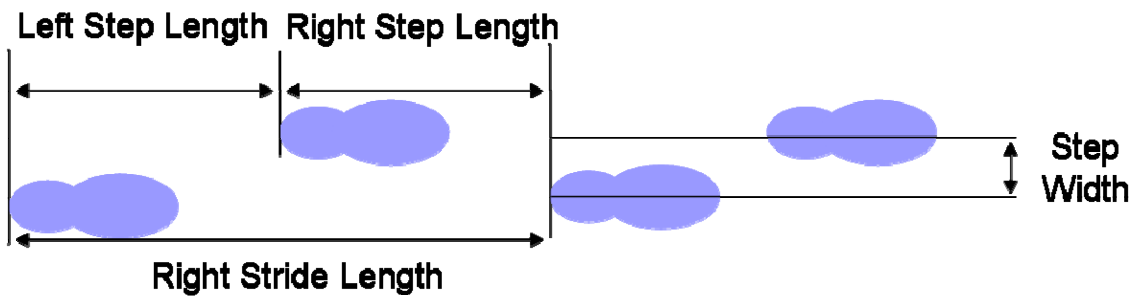

Figure 1.1: *Definition of Spatial and Temporal Characteristics of Gait*

Two steps make up each gait cycle, or each stride, and each side is roughly symmetrical in healthy, able-bodied individuals. Step width is a measure of the medial-lateral distance between feet at heel strikes, and cadence is defined as the number of steps taken per unit of time. While these parameters remain relatively symmetrical between limbs in able-bodied individuals, amputees very often adapt a unique way of walking which differs from able-bodied persons [8].

1.2. CHARACTERISTICS OF AMPUTEE GAIT

1.2.1. Transtibial Amputee Gait

There have been many studies which have been aimed at quantifying the differences between transtibial amputee gait and able-bodied gait. In general, transtibial amputees have been shown to have decreased cadence, stride length, and a slower comfortable walking speed as compared to able-bodied individuals [8-10]. Transtibial amputees also generally take longer to initiate gait and reach a steady-state walking speed than able-bodied individuals [11]. It has also been shown that transtibial amputees have wider step widths and shorter step lengths, which indicates decreased stability and less perceived security than able-bodied subjects [10]. However, amputee gait also differs from able-bodied gait in that transtibial gait has asymmetry present between the prosthetic and sound limbs. It has been shown that step time, swing time, and step length were longer while stride length and stance time were shorter on the prosthetic limb as compared to the intact limb [8, 9]. Knee flexion in the prosthetic limb has also been reported as significantly higher than the intact limb at heel strike, which can be linked to the ideal positioning of the prosthetic socket [9]. In general, the sound limb of transtibial amputees carries more weight than the amputated limb, and a strong relationship was found between the weight-bearing on the amputated limb and the strength of the residual muscles [12]. The relationship is such that the greater the strength of the residual limb, the greater the weight bearing capacity.

The leg muscles of transtibial amputees also behave differently than able-bodied individuals. In able-bodied individuals, the primary forward momentum required for walking is provided by the ankle plantarflexors [13]. In transtibial amputees, the plantarflexors are missing, so it has been proposed that this forward propulsion is provided by hyperactivity of the hip extensors [7, 9, 10]. This increased muscle activity in the hip extensors is achieved by the hamstrings, which in turn generates an above-normal knee flexor moment, which must be cancelled out by co-contracting in the quadriceps [7, 9, 14]. This co-contraction causes the net knee moment during stance to be near zero. During push-off, the hamstrings become less active, but the knee extensors remain active well into swing. These changes in muscle activation give an indication of how differently transtibial amputees walk as compared to able-bodied individuals, and it is apparent how vital the hip extensor muscles are to forward propulsion in this population. Therefore, a strength training program targeting these muscles could potentially improve not only the weight-bearing capacity of the residual limb, but it may also improve the overall walking characteristics of transtibial amputees.

1.2.2. Transfemoral Amputee Gait

The differences between transfemoral amputee gait and able-bodied individuals are similar to those between transtibial amputees and able-bodied, but the differences have been magnified in the transfemoral amputees. In terms of time-distance parameters, transfemoral amputees, as compared to both transtibial and able-bodied individuals, have a slower gait speed, decreased cadence, increased cycle time, decreased stride length, and a decreased stance phase on the prosthetic side [15-17]. Transfemoral amputees also show decreased hip flexion and extension, as well as increased hip abduction and adduction, and decreased knee flexion and extension on the intact side. In a difference from transtibial amputees, transfemoral amputees display a much larger range of motion of the pelvis and trunk. The angular range of motion of the pelvis in transfemoral amputees was significantly higher in the sagittal and frontal planes than that of able-bodied individuals, while the range of motion of the trunk was significantly higher in all three planes in the transfemoral amputees [15, 16]. The additional trunk movement significantly changes the upper body angular accelerations, which may in turn alter the individual’s global torque production, which has a profound effect on joint loading [16]. Asymmetrical joint loading of the knee and hips has been shown to have serious consequences in amputees, and will be discussed further.

The additional movement of the pelvis, which causes asymmetrical joint loading, can be classified in the following ways: (1) rotation around the transverse plane, or pelvic tilt, and (2) rotation around the sagittal plane, or hip-hiking. Hip hiking can be explained as either a compensatory technique to clear the prosthetic limb during swing, or as a weakness in the hip abductors. Weakness in the hip abductors can also be responsible for the increase in pelvic tilt, as these muscles are responsible for stabilizing the pelvis during locomotion [16]. There are also significant differences in the hamstrings, quadriceps, and tibialis anterior muscles of the sound limb of transfemoral amputees when compared to able-bodied individuals. The activation of the quadriceps and hamstring muscles of the intact limb were significantly lower than that of able-bodied individuals, while the tibialis anterior and gastrocnemius activations were significantly higher [15]. The higher activation in these muscles were attributed to the excessive power requirements of the sound ankle to compensate for the prosthetic limb. As in the transtibial amputees, there was also a high degree of co-activity in the hamstring muscles. While these insights are useful in evaluating transfemoral gait, there are several characteristics shared between transtibial and transfemoral amputees which indicate the necessity of creating a muscle strengthening protocol.

1.2.3. General Amputee Gait

There are many explanations for the differences observed between transfemoral and transtibial amputees. The quality of amputee gait can depend on many factors, including a pain-free stump, an optimally fitted socket, acceptable alignment of the prosthesis, the type of prosthetic knee or foot, and the overall health and physical condition of the amputee [7-9, 14, 18]. However, it has also been observed that the level of the amputation (i.e. the length of the residual limb) is one of the more significant contributors to the asymmetry to amputee gait [16, 19]. These studies have shown that the longer the residual limb, the more control the individual has over the prosthesis, the less movement of the trunk and pelvis, and thus the less metabolically costly.

As mentioned, movement of the pelvis can be explained by the relative strength of hip muscles, and it has been shown that the amount of atrophy in the hip abductors depends on the level of amputation; the higher the amputation level, the more muscle atrophy occurs [15, 17]. Thus, the relative strength of the thigh muscles directly contributes to the metabolic cost of walking in amputees [18, 20]. It has been very well-documented that lower-limb amputees display progressive decreases in muscle strength over time, and increases in muscle atrophy [6, 21-25]. This decrease in muscle strength can lead to changes in kinematic performance, i.e. walking ability decreases over time, but it can also have a significant impact on the joints of the hips and intact knee. Studies have shown that strength asymmetry is correlated with an increase in osteoarthritis risk in the hips, and that the incidence of osteoarthritis is greater in the intact limb than the amputated limb [4, 5, 26, 27]. These same studies also show an increase in osteoporosis in the residual limb hip, which may be a form of disuse atrophy. It is hypothesized that the reason for the increase in osteoarthritis in the intact limb is due to the unequal impact loading adopted by amputees during gait, and that this loading can be changed by a variety of factors, even walking speed [28, 29]. Therefore, in an attempt to reduce the asymmetrical loading between the limbs, and thus reduce pain caused by osteoarthritis, it is necessary to improve muscle strength in the thighs and hips of amputees.

1.3. METHODS FOR IMPROVING HIP STRENGTH

Hip strengthening programs are commonly used to improve gait in other populations aside from amputees. A study done on children with Cerebral Palsy showed that strength training of the hip and knee extensors could potentially improve walking function and alignment in patients with whom weakness was the major contributor to gait deficiencies [30]. The effect of strengthening the hip and knee flexors has also been assessed in patients with hemiparesis, or unilateral muscle weakness of the body [31, 32]. These studies have shown that as the strength of the affected plantarflexors and hip flexors increased, the participants' walking speeds increased, and their maximal levels of effort decreased, when compared to the pre-training data.

Hip strengthening programs have also been used with success in amputees. A study done with transtibial amputees used isometric strength training to improve muscle volume and strength, with the result of better prosthesis retention during walking, and a decrease in time spent in swing on the prosthetic limb [33]. A different study used isokinetic strength training in transtibial amputees, with the result of improved muscle strength and patient-reported improvements in gait [22]. One final study combined psychological and physiotherapeutic treatment to improve gait in transfemoral amputees. This particular study was aimed at integrating the prosthesis into normal movements and increasing body-awareness. This study ultimately showed that the subjects' comfortable walking speed increased, there was more symmetry at the hip joint, more muscle work was done on the amputated side, and the lower back pain experienced by the amputees disappeared [10, 34].

This thesis will attempt to evaluate the efficacy of the hip strengthening training program developed by Dr. Lee Nolan at Karolinska Institutet, in Sweden [35]. It does so by evaluating the kinematics of seven lower-limb amputees (four TT, three TF) who participated in a ten-week training protocol, as compared to eight amputees (three TT, five TF) in a control group, who continued their normal habits.

1.4. METHODS FOR TIME NORMALIZING GAIT DATA

Locomotion is typically assumed to be periodic, so for analysis purposes, data are frequently broken into gait cycles. However, the duration and timing of gait cycle events can vary, even under the steadiest of conditions [36, 37]. Therefore, in order to assess average behavior over several gait cycles or from different populations, it is first necessary to temporally align the data. There are several techniques employed on time-series data, with different methods preferred depending on the application. A description of the most frequently used techniques to normalize biomechanical data follows.

1.4.1. Linear Length Normalization

The most common technique for temporally aligning gait data is by expressing the data in percentages, from 0 to 100%, of the gait cycle. This approach linearly expands or compresses the time axis of each gait cycle, such that all gait cycles have the same length. While this technique removes the temporal differences caused by changes in the length of a gait cycle, temporal differences between gait events (e.g. heel strikes, toe-offs), may still exist. Thus, movement patterns averaged over multiple gait cycles may express reduced peak magnitudes and increased standard deviations due to inter- and intra-cycle variability in timing [37, 38].

1.4.2. Dynamic Time Warping

Dynamic time warping is a technique used in aligning various types of biometric data [39, 40], and non-linearly compresses the time-axis data of a trajectory. Dynamic time warping aligns a test trajectory to a target trajectory by minimizing the difference in <u>intensity</u> between the two curves. This technique can also be applied in a piecewise manner, once the data has been broken into distinct subphases of gait. While dynamic time warping produces successful alignment when the two curves differ in timing but not intensity, the technique produces poor temporal alignment when the subphases of gait exhibit systematic intensity differences between the test and target curves [41]. One other potential drawback to this technique is the reliance of the constraints placed on the system by the user. If the constraints are too lenient, the data may be distorted, but alignment may not be achieved if the constraints are too harsh.

1.4.3. Derivative Dynamic Time Warping

Derivative dynamic time warping is a technique developed to address the limitations of the minimization criteria present in dynamic time warping. This technique also non-linearly compresses or expands the time axis of a test trajectory to a target trajectory, but it determines the temporal alignment which minimizes the difference between the <u>estimated local derivatives</u> of both trajectories. With this technique, the temporal alignment is successful unless the shape of the two curves is drastically different. As with dynamic time warping, the final alignment between the two curves is highly dependent on user constraints.

1.4.4. Piecewise Linear Length Normalization

Piecewise linear length normalization is a curve registration technique which expands or compresses the time axis of the target curve in a linear manner between specified points of interest along the gait cycle [38]. The points of interest can be any characterizing points within the gait cycle, as long as it is possible to identify these features in all subjects and experimental conditions. Examples of these could be peaks, valleys, or gait events. This technique also allows for greater insight into temporal and intensity differences between gait cycle data throughout the entire cycle.

Therefore, based on the advantages and disadvantages of the described alignment techniques, PLLN was chosen to analyze the amputee data set. This technique will not only align the data, but it can also provide added insight into the movement patterns adopted by amputees, and how this changes as a result of a training program.

1.5. AN INTRODUCTION TO OPENSIM

In order to create the kinematic curves to be analyzed, an open-source software called OpenSim was used to evaluate the experimental motion capture data from the amputee data set. OpenSim is a platform for modeling, simulating, and analyzing the neuromusculoskeletal system [42]. Major benefits of OpenSim are: (1) the ability to create subject-specific models of motion, (2) its ability to analyze experimental motion capture data in all three planes, (3) the ability to calculate joint moments and powers, and (4) the ability to create forward dynamic simulations of walking. It is for the first two reasons that OpenSim was chosen as the analysis tool for the amputee data set.

The first step in assessing a subject's motion is to first scale the general musculoskeletal model to match the anthropometry (physical measurements) of an individual subject. The dimensions of each body segment are scaled based on relative distances between pairs of markers obtained experimentally and those of the corresponding virtual marker locations in the model (Figure 1.2). In this model, the torso is defined as a rigid body from the bottom of the spinal column to the top of the skull. To simplify the model further, there are also no arms present. The knees and ankles are defined as one-degree of freedom joints, while the hips, pelvis, and torso have three-degrees of freedom.

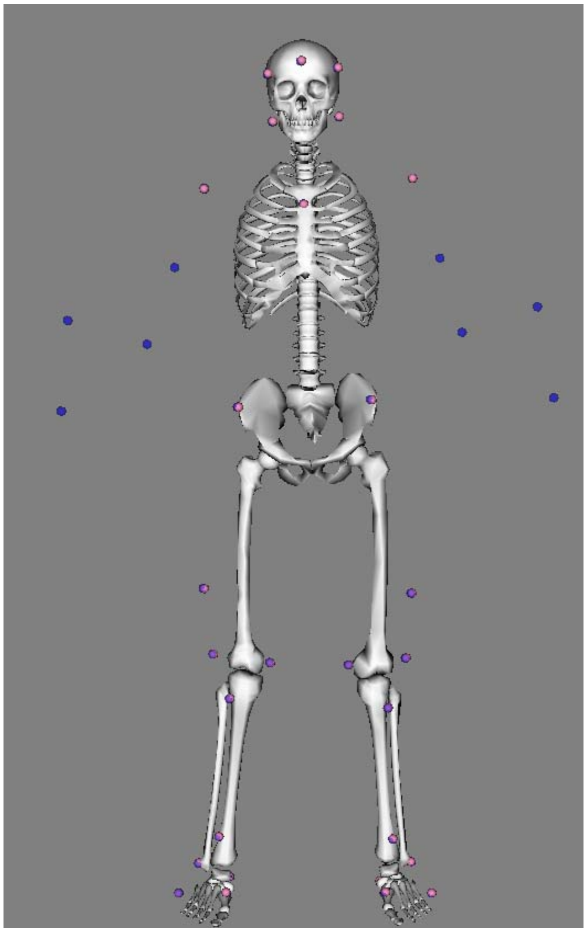

Figure 1.2*: Scaling the Generic Model in OpenSim. Experimental markers are indicated in blue, while virtual model markers are pink.*

Once the model has been scaled to match an individual subject, joint angles and positions can be determined for each experimental trial. This step is referred to as performing inverse kinematics. In OpenSim, this step is formulated as a least-squares problem which minimizes the difference between the measured marker location and the model's virtual marker locations. Therefore, in each frame of the experimental data, the weighted squared error is minimized.

$$\textit{Squared Error} = \sum_{i=1}^{\text{markers}} w_i \left(\overrightarrow{x_i}^{\text{subject}} - \overrightarrow{x_i}^{\text{model}} \right)^2 \tag{1}$$

In this equation, $\vec{x}_i^{\text{subject}}$ and $\vec{x}_i^{\text{model}}$ are the three-dimensional positions of the *i*th marker for the subject and model, respectively, and w_i is a factor which allows different markers to be weighted differently. Weighting is used to put relative weights on each of the different markers. For example, boney landmarks (i.e. knees, ankles, anterior superior iliac spine) are given greater weightings than fleshy landmarks (i.e. thighs or calves) because the degree of certainty for correct marker placement is higher. Because the weight values are relative, a value of 1 for a fleshy marker compared to a value of 10 for a boney maker would have the same effect as putting vales of 0.1 and 1, respectively. When the weighted squared error is minimized, the coordinate values which produced this error are reported for the frame. Once the coordinate values have been determined for every frame, the trial results are then exported into MATLAB for statistical analysis.

1.6. THESIS ORGANIZATION

Chapter 2 of this thesis covers the refinement of a gait analysis technique, piecewise linear length normalization (PLLN). This study examined how specific gait events, which align with traditional subphases of the gait cycle, can be used as points of interest in PLLN. This study used data from healthy adult males in both normal walking conditions and with a simulated impairment caused by the addition of a restrictive knee-brace. Chapter 3 evaluates the kinematic performance of amputees prior to and after a special training program. The results were analyzed using standard spatiotemporal metrics, OpenSim, and PLLN. Chapter 4 summarizes the findings and explores potential future work and experiments.

1.7. LIST OF REFERENCES

1. Perry, J., *Gait Analysis*. 1992, Slack, Inc.: Thorofare, NJ. p. 11-15.
2. Owings, M.F. and L.J. Kozak, *Ambulatory and inpatient procedures in the United States, 1996.* Vital and health statistics. Series 13, Data from the National Health Survey, 1998(139): p. 1-119.
3. Ziegler-Graham, K., E.J. MacKenzie, P.L. Ephraim, T.G. Travison, and R. Brookmeyer, *Estimating the Prevalence of Limb Loss in the United States: 2005 to 2050.* Archives of Physical Medicine and Rehabilitation, 2008. **89**(3): p. 422-429.
4. Burke, M.J., V. Roman, and V. Wright, *Bone and joint changes in lower limb amputees.* Annals of the Rheumatic Diseases, 1978. **37**(3): p. 252-254.
5. Kulkarni, J., J. Adams, E. Thomas, and A. Silman, *Association between amputation, arthritis and osteopenia in British male war veterans with major lower limb amputations.* Clinical Rehabilitation, 1998. **12**(4): p. 348-353.
6. Renstrom, P., G. Grimby, and E. Larsson, *Thigh muscle strength in below-knee amputees.* Scandinavian Journal of Rehabilitation Medicine, 1983. **15**(SUPPL.9): p. 163-173.
7. Winter, D.A. and S.E. Sienko, *Biomechanics of below-knee amputee gait.* Journal of Biomechanics, 1988. **21**(5): p. 361-367.
8. Kovac, I., V. Medved, and L. Ostojic, *Spatial, temporal and kinematic characteristics of traumatic transtibial amputees' gait.* Collegium Antropologicum. **34**(SUPPL. 1): p. 205-213.
9. Isakov, E., O. Keren, and N. Benjuya, *Trans-tibial amputee gait: Time-distance parameters and EMG activity.* Prosthetics and Orthotics International, 2000. **24**(3): p. 216-220.
10. Su, P.F., S.A. Gard, R.D. Lipschutz, and T.A. Kuiken, *Gait characteristics of persons with bilateral transtibial amputations.* Journal of Rehabilitation Research and Development, 2007. **44**(4): p. 491-501.
11. Tokuno, C.D., D.J. Sanderson, J.T. Inglis, and R. Chua, *Postural and movement adaptations by individuals with a unilateral below-knee amputation during gait initiation.* Gait and Posture, 2003. **18**(3): p. 158-169.
12. Nadollek, H., S. Brauer, and R. Isles, *Outcomes after trans-tibial amputation: the relationship between quiet stance ability, strength of hip abductor muscles and gait.* Physiotherapy research international : the journal for researchers and clinicians in physical therapy, 2002. **7**(4): p. 203-214.
13. Winter, D.A., *Biomechanics and Motor Control of Human Movement*. 2005, Hoboken, NJ: John Wiley & Sons, Inc.
14. Soares, A.S.O.D.C., E.Y. Yamaguti, L. Mochizuki, A.C. Amadio, and J.C. Serraso, *Biomechanical parameters of gait among transtibial amputees: A review.* Sao Paulo Medical Journal, 2009. **127**(5): p. 302-309.
15. Bae, T.S., K. Choi, D. Hong, and M. Mun, *Dynamic analysis of above-knee amputee gait.* Clinical Biomechanics, 2007. **22**(5): p. 557-566.

16. Goujon-Pillet, H., E. Sapin, P. Fodac, and F. Lavaste, *Three-Dimensional Motions of Trunk and Pelvis During Transfemoral Amputee Gait.* Archives of Physical Medicine and Rehabilitation, 2008. **89**(1): p. 87-94.
17. Jaegers, S.M.H.J., J.H. Arendzen, and H.J. De Jongh, *Prosthetic gait of unilateral transfemoral amputees: A kinematic study.* Archives of Physical Medicine and Rehabilitation, 1995. **76**(8): p. 736-743.
18. Schmalz, T., S. Blumentritt, and R. Jarasch, *Energy expenditure and biomechanical characteristics of lower limb amputee gait:: The influence of prosthetic alignment and different prosthetic components.* Gait & Posture, 2002. **16**(3): p. 255-263.
19. Baum, B.S., B.L. Schnall, J.E. Tis, and J.S. Lipton, *Correlation of residual limb length and gait parameters in amputees.* Injury, 2008. **39**(7): p. 728-733.
20. Waters, R.L. and S. Mulroy, *The energy expenditure of normal and pathologic gait.* Gait and Posture, 1999. **9**(3): p. 207-231.
21. Isakov, E., H. Burger, M. Gregoria, and C. Marinaek, *Isokinetic and isometric strength of the thigh muscles in below-knee amputees.* Clinical Biomechanics, 1996. **11**(4): p. 233-235.
22. Klingenstierna, U., P. Renstrom, G. Grimby, and B. Morelli, *Isokinetic strength training in below-knee amputees.* Scandinavian Journal of Rehabilitation Medicine, 1990. **22**(1): p. 39-43.
23. Renstrom, P., G. Grimby, B. Morelli, and B. Palmertz, *Thigh muscle atrophy in below-knee amputees.* Scandinavian Journal of Rehabilitation Medicine, 1983. **15**(SUPPL.9): p. 150-162.
24. Renstrom, P.A.F.H., H. Alaranta, and T. Pohjolainen, *Review: Leg strengthening of the lower limb amputee.* Critical Reviews in Physical and Rehabilitation Medicine, 1995. **7**(1): p. 11-32.
25. Sherk, V.D., M.G. Bemben, and D.A. Bemben, *Interlimb Muscle and Fat Comparisons in Persons With Lower-Limb Amputation.* Archives of Physical Medicine and Rehabilitation. **91**(7): p. 1077-1081.
26. Lloyd, C.H., S.J. Stanhope, I.S. Davis, and T.D. Royer, *Strength asymmetry and osteoarthritis risk factors in unilateral trans-tibial, amputee gait.* Gait and Posture. **32**(3): p. 296-300.
27. Tugcu, I., I. Safaz, B. Yilmaz, A.S. GÃ¶ktepe, M.A. Taskaynatan, and K. Yazicioglu, *Muscle strength and bone mineral density in mine victims with transtibial amputation.* Prosthetics and Orthotics International, 2009. **33**(4): p. 299-306.
28. Nolan, L., A. Wit, K. DudziÃ±ski, A. Lees, M. Lake, and M. WychowaÃ±ski, *Adjustments in gait symmetry with walking speed in trans-femoral and trans-tibial amputees.* Gait and Posture, 2003. **17**(2): p. 142-151.
29. Radin, E.L., H.G. Parker, J.W. Pugh, R.S. Steinberg, I.L. Paul, and R.M. Rose, *Response of joints to impact loading -- III: Relationship between trabecular microfractures and cartilage degeneration.* Journal of Biomechanics, 1973. **6**(1): p. 51-54, IN9-IN11, 55-57.
30. Damiano, D.L., A.S. Arnold, K.M. Steele, and S.L. Delp, *Can strength training predictably improve gait kinematics? A pilot study on the effects of hip and knee*

extensor strengthening on lower-extremity alignment in cerebral palsy. Physical Therapy, 2010. **90**(2): p. 269-279.
31. Jorgensen, J.R., D.T. Bech-PÃ¨dersen, P. Zeeman, J. SÃ¸rensen, L.L. Andersen, and M. SchÃ¶nberger, *Effect of intensive outpatient physical training on gait performance and cardiovascular health in people with hemiparesis after stroke.* Physical Therapy, 2010. **90**(4): p. 527-537.
32. Milot, M.H., S. Nadeau, D. Gravel, and D. Bourbonnais, *Effect of increases in plantarflexor and hip flexor muscle strength on the levels of effort during gait in individuals with hemiparesis.* Clinical Biomechanics, 2008. **23**(4): p. 415-423.
33. Kegel, B., E.M. Burgess, T.W. Starr, and W.K. Daly, *Effects of isometric muscle training on residual limb volume, strength, and gait of below-knee amputees.* Physical Therapy, 1981. **61**(10): p. 1419-1426.
34. Sjodahl, C., G.B. Jarnlo, and B.M. Persson, *Gait improvement in unilateral transfemoral amputees by a combined psychological and physiotherapeutic treatment.* Journal of Rehabilitation Medicine, 2001. **33**(3): p. 114-118.
35. Nolan, L., *A Training Program to Improve Hip Strength in Lower Limb Amputees.* under review.
36. Chao, E.Y., R.K. Laughman, E. Schneider, and R.N. Stauffer, *Normative data of knee joint motion and ground reaction forces in adult level walking.* Journal of Biomechanics, 1983. **16**(3): p. 219-233.
37. Forner-Cordero, A., H.J.F.M. Koopman, and F.C.T. Van Der Helm, *Describing gait as a sequence of states.* Journal of Biomechanics, 2006. **39**(5): p. 948-957.
38. Sadeghi, H., P. Allard, K. Shafie, P.A. Mathieu, S. Sadeghi, F. Prince, and J. Ramsay, *Reduction of gait data variability using curve registration.* Gait & posture, 2000. **12**(3): p. 257-264.
39. Boulgouris, N.V., K.N. Plataniotis, and D. Hatzinakos. *Gait recognition using dynamic time warping*. in *2004 IEEE 6th Workshop on Multimedia Signal Processing*. 2004.
40. Cho, H., G.A. Ojemann, D. Corina, and L. Shapiro. *Detection of Neural Activity in Event-related fMRI using Wavelets and Dynamic Time Warping*. in *Proceedings of SPIE - The International Society for Optical Engineering*. 2003.
41. Helwig, N.E., S. Hong, E.T. Hsiao-Wecksler, and J.D. Polk, *Methods to temporally align gait cycle data.* Journal of Biomechanics, 2011. **44**(3): p. 561-566.
42. Delp, S.L., F.C. Anderson, A.S. Arnold, P. Loan, A. Habib, C.T. John, E. Guendelman, and D.G. Thelen, *OpenSim: Open-source software to create and analyze dynamic simulations of movement.* IEEE Transactions on Biomedical Engineering, 2007. **54**(11): p. 1940-1950.

CHAPTER 2: PIECEWISE LINEAR LENGTH NORMALIZATION USING GAIT EVENTS

2.1. INTRODUCTION

Time normalization of kinematic, kinetic, and/or electromyography (EMG) gait data to percent gait cycle is a common practice of assessing average behavior over several gait cycles, or comparing gait patterns from different populations. This process assumes that gait cycles are periodic and assigns consecutive ipsilateral heel-strikes to 0 and 100% gait cycle, respectively. This approach generally ignores timing variability in movement patterns, both between and within gait cycles, e.g., variations in peak value times or toe-off times. Thus movement data averages over multiple gait cycles may express reduced peak magnitudes and results in increased standard deviations due to inter- and intra-cycle variability in timing [1, 2].

Although gait researchers often acknowledge these alignment problems, relatively few studies have attempted to address them. If used, separation between stance and swing phases by aligning data to toe-off is the most common approach. A few have tried aligning gait data at multiple instances throughout the gait cycle, such as peak values [1], arbitrary states [2], or across the entire gait cycle [3]. These works did not consider alignment based on clinically-relevant gait events that identify sub-phases of the gait cycle, which may have resulted in overlooking subtle gait characteristics present in the data. Alignment by gait events could also allow comparison across joints and gait parameters, which may not be possible with the other techniques. Further, these works were interested in reducing temporal differences in order to better explore intensity differences in gait parameter magnitudes. They did not consider that additional information from the system may be obtained by examining the temporal shifts (i.e. changes in timing) necessary to make these alignments.

We recently explored multiple methods for time normalizing gait data and have found piecewise linear length normalization (PLLN) to be a preferable technique for removing timing variability between discrete points of interest throughout the gait cycle [4]. PLLN is essentially curve registration that compresses or expands the time axis of a cycle to-be-aligned with a target data set. Alignments are done using linear interpolation between specified points of interest along the gait cycle.

In this paper, we time normalized gait data using PLLN to specific gait events, as based on sub-phases of the gait cycle. We also illustrate the potential utility of examining temporal shift-signatures, i.e., temporal differences which highlight the direction and magnitude of temporal shifts necessary for alignment.

2.2. METHODS

2.2.1. Participants

Walking data from ten healthy males, age 21 ± 2 (SD) years, height 1.79 ± .09 meters, and mass 81 ± 9 kg participated in the study [5]. Subjects had no gait impairments or history of significant injury to the lower limbs or joints. All subjects were also experienced treadmill walkers, and indicated right leg dominance. All procedures were approved by the University Institutional Review Board, and all participants gave informed consent.

2.2.2. Experimental Procedure

Kinematic data were collected using a six-camera infrared camera system (VICON, Oxford, UK; Model 460) sampling at 120 Hz, and were filtered using a low-pass, fourth-order Butterworth filter. Force data were captured continuously during the three-minute trials while the subjects walked on a treadmill (Proform, Logan, UT, USA; Model PFTL05052) for each testing condition. The subjects walked at a self-selected speed under two conditions: (1) normal, non-braced, and (2) braced right knee. The addition of the knee brace (DonJoy, Vista, CA, USA; model 81,099) simulated an injury or other irregular gait pattern by preventing knee flexion. Sagittal plane joint angles, joint centers, and centers of mass were calculated from the motion capture data

2.2.3. Piecewise Linear Length Normalization

2.2.3.1. Defining the Gait Events for use in Normalization

We defined seven sub-phases of gait from eight gait events (Figure 2.1) [6]. Loading response (LR) was defined as ipsilateral heel strike (IHS[1]) to contralateral limb toe-off (CTO). Mid-stance (MS) was defined as CTO to weight alignment over the forefoot (WA), which occurred when the center of mass of the torso was aligned with the joint center of the ipsilateral toes. Terminal stance (TS) lasted from WA until contralateral heel strike (CHS). CHS began pre-swing (PS), which lasted until ipsilateral toe-off (ITO). Initial Swing (ISw) began at ITO and continued until the ipsilateral toe was aligned with the contralateral heel (THA). THA indicated the beginning of Mid-Swing (MSw), which continued until the sagittal plane ipsilateral knee aligned with the ipsilateral ankle (KA).

Terminal swing (TSw) then began, and continued until the ipsilateral heel again struck the ground (IHS[2]).

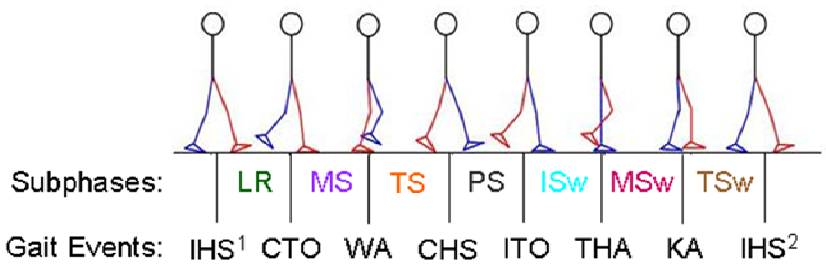

Figure 2.1: The *seven sub-phases of gait as based on gait events: Loading Response (LR), Mid-Stance (MS), Terminal Stance (TS), Pre-Swing (PS), Initial Swing (ISw), Mid-Swing (MSw), and Terminal Stance (TSw).*

2.2.3.2. Creating the Consensus Curve

A consensus data set was created from the un-braced angle data, by determining the average timing, in % gait cycle, for each gait event of the un-braced data sets. Two matrices, one for each side (left and right), were created for each subject with the rows representing each cycle, and each of the eight columns containing the frame index for each gait event. The time, in frames, for each of the sub-phases was then calculated for each of the gait cycles. The timings for each sub-phase of each cycle were then converted into a percentage of the total gait cycle. These values were then averaged and used to create a subject-specific timing matrix.

Once the average timings for each subject were calculated, it was possible to determine consensus average timings across all subjects (Table 2.1). These consensus timings were then used to linearly warp each trial's kinematic curves for a given subject. For example, if a subject spent, on average, 14% of the gait cycle in loading response, but the consensus timing was 18%, the time scale for this subject's loading response was linearly shifted to match the consensus value. Once all of a subject's un-braced gait cycles were warped to the consensus timing values, the curves (e.g. ankle, knee, and hip) were averaged to create an average curve for the given subject. The mean of the ten subjects' average curves became the consensus curve (Figure 2.2).

2.2.3.3. Aligning the Knee-Braced Data

The average timings for each of the sub-phases were found for the braced data in the same manner as that of the un-braced data. These values were recorded for use in the temporal shift calculations. The consensus values from the un-braced data set, recognized as the normative values, were then used to align each subject's braced kinematic curves, and these newly aligned curves were then averaged to generate a subject's characteristic braced curves (Figure 2.2). Temporal and intensity differences (test minus target values) for each subject's curve relative to the consensus curve were then calculated.

2.3. RESULTS

Average timings for the gait events for both the un-braced and braced data set for both right and left legs can be seen in Table 2.1.

Table 2.1: *Consensus timings (± standard deviation) for subphases across all subjects, both left and right legs. Reported are the consensus timings for the unbraced data (in % Gait Cycle) and the average braced data timings prior to alignment by PLLN.*

Trial	Leg	Loading Response	Mid-Stance	Terminal Stance	Pre-Swing	Initial Swing	Mid-Swing	Terminal Swing
Unbraced	Right	18.1 ± 1.1	13.8 ± 1.8	18.0 ± 2.0	18.0 ± 0.9	9.6 ± 0.8	15.3 ± 1.1	7.2 ± 2.2
	Left	18.1 ± 1.1	13.4 ± 1.8	18.5 ± 1.6	18.5 ± 1.1	9.5 ± 0.7	9.2 ± 1.1	13.2 ± 2.6
Braced	Right	14.5 ± 1.0	11.2 ± 2.6	20.2 ± 2.3	15.5 ± 3.4	12.5 ± 3.4	16.1 ± 0.7	10.0 ± 2.4
	Left	15.6 ± 2.0	14.9 ± 3.0	23.4 ± 2.1	14.5 ± 1.0	9.1 ± 1.3	9.1 ± 1.1	13.1 ± 2.9

As can be seen from the table, bracing resulted in noticeable average temporal shifts. For the right, braced leg, there were significant changes in every subphase of gait ($p<0.05$), with an decrease of 20% in loading response, 19% decrease in mid-stance, 12% increase in terminal stance, 14% decrease in pre-swing, 30% increase in initial swing, 5% increase in mid-swing, and 39% increase in swing. Meanwhile, the left leg showed significant temporal changes in loading response, terminal stance, and pre-swing, with an decrease of 14%, increase of 26%, and decrease of 22%, respectively. Bracing also had an impact on the degree of symmetry between the limbs. Prior to bracing, both legs were nearly symmetrical in phase timing, with only the mid-swing and terminal-swing phases showing significant differences between the legs ($p<0.05$). After bracing, however, significant asymmetries were present between the two limbs in all but loading response and pre-swing phases. For example, the average difference between the limbs in initial swing prior to bracing was only 0.1 % GC, while after bracing, the difference was 3.4 % GC.

Bracing also had a significant impact on the shape of the kinematic curves, and PLLN improved the alignment of the motion patterns (Figure 2.2). It is important to note that even after alignment by PLLN, the peak values of the joint angle curves do not align.

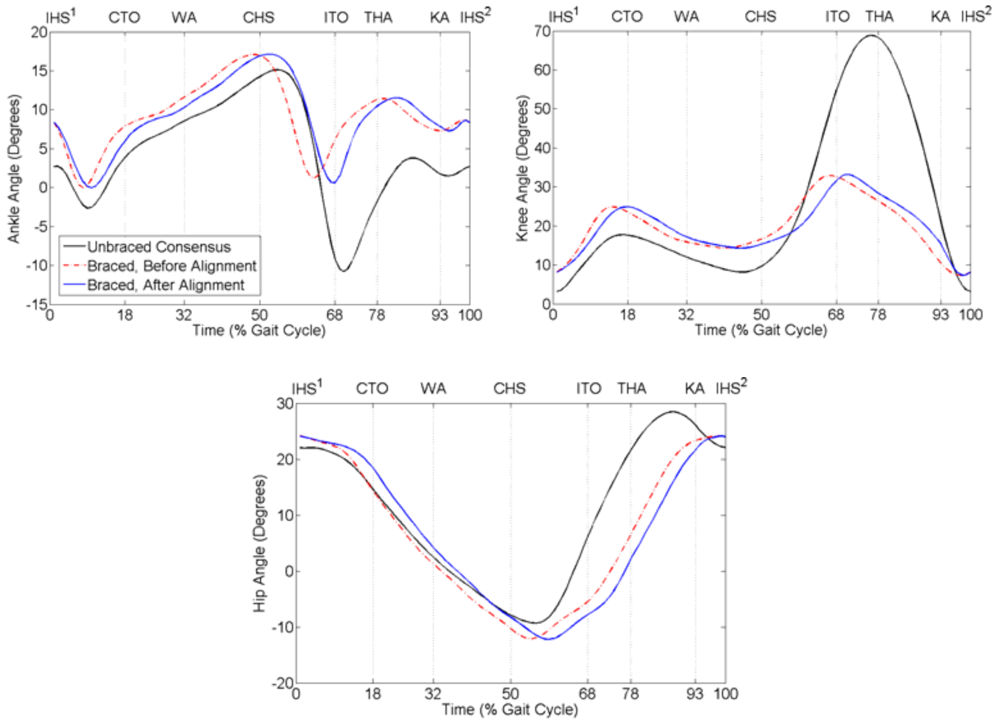

Figure 2.2: *Sample subject trajectories for the right leg ankle, knee, and hip sagittal plane joint angles. Shown curves are averages of forty gait cycles from one subject, with the exception of the black solid line, which is the consensus curve (all curves from all subjects after PLLN alignment). The other curves represent the knee-braced before (red dashed) and after (blue solid) alignment using PLLN. Vertical dashed lines indicate key consensus gait event timings.*

The intensity and temporal differences for all ten subjects were calculated, and a representative curve can be seen in Figure 2.3. This particular subject spent 4% less time (in % GC) in loading response when the knee was braced as compared to the average unbraced data (i.e. this subject spent an average of 14% of the gait cycle in loading response when the right knee was braced). This particular subject also spent 2% more time in terminal stance and 2 % more time initial swing when the right knee was braced than the consensus unbraced average.

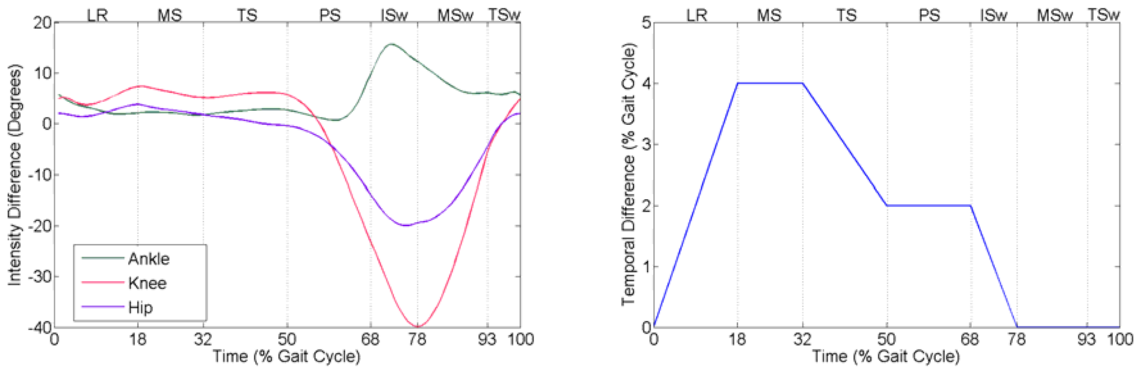

Figure 2.3: *Intensity and temporal differences for the right side of one subject. Intensity plots are given for the right ankle (solid green), knee (solid red), and hip (solid purple).*

Alignment with PLLN significantly changed the intensity differences for each kinematic curve when compared to the unwarped data (Figure 2.4). For example, in the right ankle curves, the maximum intensity difference decreased by 3.5° in the warped curve as compared to the unwarped curve, while the minimum intensity difference increased by 8.3°.

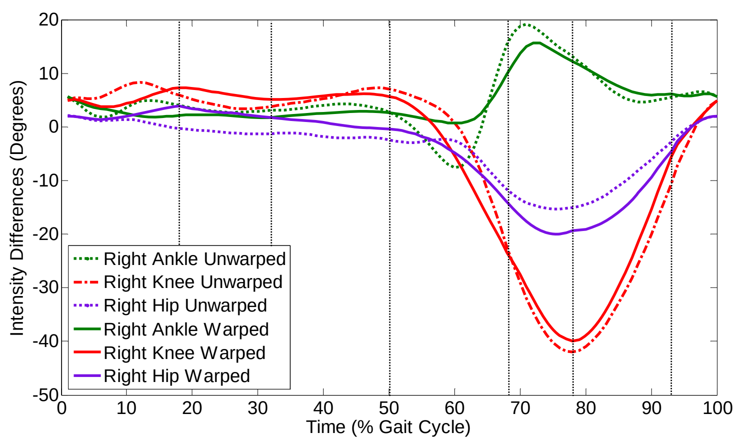

Figure 2.4: *Changes in intensity differences between the warped and unwarped data set in one subject. Dashed lines indicated unwarped data, while heavy solid lines represent intensity differences after alignment using PLLN. Vertical dashed lines indicate timing of consensus gait events.*

2.4. DISCUSSION

Use of the PLLN technique provided additional insight into the effect of bracing one knee in healthy adult males by giving more detailed information about temporal shifts in gait patterns. The right, braced leg showed a decreased time spent in loading response, mid-stance, and pre-swing (20%, 19%, 14%, respectively), and an increased time in terminal stance, initial swing, mid-swing, and terminal swing (12%, 5%, and 39%, respectively) as compared to the unbraced trials (see Table 2.1 for changes in terms of % GC). The left leg showed a 14% decrease in the loading response phase and a 26% increase in terminal stance and 22% increase in pre-swing. Each of these changes represented a physical adaptation to the perturbation caused by the knee brace. For example, a decreased time in loading response indicates a need for faster weight acceptance, while a decrease in mid-stance and pre-swing implies the individuals are progressing over their stationary foot faster, and wish to transfer their weight to the other limb earlier. The asymmetries evident between the limbs indicated a desire of the subjects to spend more time in stance on the unbraced limb when compared to the braced limb, and more time in swing on the braced side. The temporal data also indicated the braced data typically led comparable events in the consensus data for that side, while the unbraced side remained relatively constant between the two conditions.

Alignment of the motion patterns was also improved through the use of PLLN (Figure 2.2). The improved alignment allowed for examination of intensity differences in the three joint angles throughout the gait cycle, rather than at specific points as commonly reported. By using gait events to normalize the data, it is possible to align the data across all the joint angles, which would not be possible if the peaks of one kinematic profile were chosen as the points of interest during normalization. One final observation is that after alignment by PLLN, the peaks of the joint angle curves, especially apparent in the ankle joint, do not align to the consensus curves, which may provide greater clinical relevance to the interpreted data.

2.5. CONCLUSIONS

By specifically selecting clinically-relevant gait events, it may be possible to provide improved interpretation of gait behaviors, especially behaviors that deviate from normative patterns. By capturing and examining the temporal differences that were necessary to expand or contract the time axis of the given cycle relative to the consensus pattern, we are provided with greater insight into more subtle timing differences within the gait cycle. These timing differences may provide useful information about impaired control mechanisms of gait.

2.6. LIST OF REFERENCES

1. Sadeghi, H., P. Allard, K. Shafie, P.A. Mathieu, S. Sadeghi, F. Prince, and J. Ramsay, *Reduction of gait data variability using curve registration.* Gait & posture, 2000. **12**(3): p. 257-264.
2. Forner-Cordero, A., H.J.F.M. Koopman, and F.C.T. Van Der Helm, *Describing gait as a sequence of states.* Journal of Biomechanics, 2006. **39**(5): p. 948-957.
3. Chau, T., S. Young, and S. Redekop, *Managing variability in the summary and comparison of gait data.* Journal of NeuroEngineering and Rehabilitation, 2005. **2**.
4. Helwig, N.E., S. Hong, E.T. Hsiao-Wecksler, and J.D. Polk, *Methods to temporally align gait cycle data.* Journal of Biomechanics, 2011. **44**(3): p. 561-566.
5. Shorter, K.A., J.D. Polk, K.S. Rosengren, and E.T. Hsiao-Wecksler, *A new approach to detecting asymmetries in gait.* Clinical Biomechanics, 2008. **23**(4): p. 459-467.
6. Perry, J., *Gait Analysis*. 1992, Slack, Inc.: Thorofare, NJ. p. 11-15.

CHAPTER 3: THE EFFECT OF A HIP STRENGTH IMPROVING PROGRAM ON GAIT IN LOWER-LIMB AMPUTEES

3.1. INTRODUCTION

It is well-documented that amputee gait tends to be distinctly different from able-bodied gait. In general, amputees have a slower self-selected comfortable walking speed, decreased stride length, decreased cadence, and increased cycle time [1-6]. Amputee gait also displays a high degree of asymmetry between the prosthetic and sound limbs. Step time, swing time, and step length tend to be longer, while stride length and stance time are shorter on the prosthetic side as compared to the intact limb [3, 5]. In general, the sound limb carries more weight than the amputated limb; although, the weight bearing capacity on the prosthetic side has been found to increase as the strength of the residual muscles increases [7]. The increased and repetitive loading on the intact limb during walking can lead to pain and joint degradation in the intact limb [8, 9].

It has also been observed that amputees with highly atrophied hip-stabilizing muscles in the residual limb walked with an extreme lateral bending of the trunk during swing, thus the relative strength of the thigh muscles directly contributes to the metabolic cost of walking in amputees [2, 7, 10-12]. It has been widely documented that lower-limb amputees display a progressive decrease in muscle strength over time, as well as a progressive increase in muscle atrophy, primarily in the residual limb [13-17]. This muscle atrophy has been associated with changes in gait strategy and the loss of ability to strongly contract the distal muscles of the residual limb.

Other studies have shown that strong hip muscles correlate strongly with improved gait performance, as well as decreased pelvic tilt and out-of-plane movement of the torso [2, 7, 10]. This leads to the supposition that by increasing the hip strength of amputees, it is possible to improve gait performance, potentially decrease the metabolic cost associated with walking, and even prevent joint degradation through reducing asymmetrical loading [18-20].

Because of the compensatory strategies mentioned above, as well as the physiological changes due to amputation (i.e. muscle atrophy), amputees tend to display decreased endurance, increased fatigue while walking, and feel unable to run and jump [21]. Thus, they do not participate in recreational and sports activities. By designing a training program for lower limb amputees to strengthen muscles which are usually weak, it may enable running in individuals who may otherwise feel unable to participate in recreational activities.

Hip strengthening programs have been used to improve gait, but not necessarily running, in other populations. For example, a study done on children with Cerebral Palsy showed that strength training of the hip and knee extensors could improve walking function and alignment in patients with whom weakness was the major contributor to gait deficiencies [22]. The effect of strengthening the hip and knee flexors has been assessed in patients with hemiparesis, which is the unilateral weakness of the body [23, 24]. These studies have shown that as the strength of the affected plantarflexors and hip flexors increased, the participants' walking speeds increased and their maximal levels of effort decreased when compared to the pre-training data.

Muscle strengthening programs have been used successfully in amputees. One study used isometric strength training to improve muscle volume and strength in the residual limb of transtibial amputees. This training resulted in better prosthesis retention during walking, and a decrease in time spent in swing on the prosthetic limb [25]. Another study used isokinetic strength training in transtibial amputees, with the result of improved muscle strength in the knee extensors of the residual limb and patient-reported improvements in gait [14]. A third study combined psychological and physiotherapeutic treatment to improve gait in transfemoral amputees. This particular study was aimed at integrating the prosthesis into normal movements and increasing body-awareness. This study ultimately showed that when the subject's comfortable walking speed increased, there was more hip joint symmetry, more muscle work was done on the amputated side, and lower back pain disappeared [6, 26]. Therefore, because hip strengthening programs in other populations, and muscle strengthening programs in amputees, have shown success in improving gait performance, a hip strength improving program should have a beneficial impact on the gait of lower-limb amputees.

The goals of this project were to determine the plausibility of using a hip strength improving program to improve kinematic performance, decrease the metabolic cost associated with walking, and determine if the training is sufficient to enable running in lower-limb amputees. Seventeen subjects were randomly separated into a no-intervention control group and a hip strength training group. An initial study found that, for participants of the training group, the hip strength was improved, oxygen consumption decreased, and only one subject was not able to run after the ten week training period [27]. In the control group, either no changes were observed, or in some cases, muscle strength decreased and oxygen consumption increased. The study presented in this paper examines whether there were changes in kinematic walking gait metrics as a consequence of the hip strengthening program and also if there were changes in gait between subjects that were eventually able to run versus those that could not.

3.2. METHODS

The experimental protocol for the training program can be found in [27]. Participant demographics, experimental procedure as it relates to kinematic performance, and the data analysis techniques used in the thesis will be briefly summarized.

3.2.1. Participants

Seventeen lower-limb amputees were included in this study, assigned to either a control (n = 8) or training group (n = 9). Participants were matched as closely as possible by gender, level of amputation, and number of years as an amputee. Of the eight in the control group, three were transtibial (TT) and five were transfemoral (TF), while in the training group, four were TT, three were TF, and two were bilateral, one side TF and the other side TT. The data from the two bilateral training group amputees are not included in this analysis. All participants had amputations resulting from tumor, trauma, or congenital problems and all walked with their prosthesis daily. All participants were amputees for at least one year prior to the study. The mean age (± standard deviation), height, body mass, and years as an amputee were 41.1 ± 8.4 years, 1.8 ± 0.12 meters, and 91.5 ± 25.5 kg, and 8.2 ± 9.2 years, respectively for the training group. The control group had a mean age, height, body mass, and years as an amputee of 49.0 ± 9.1 years, 1.7 ± 0.08 meters, and 76.2 ± 14.9 kg, and 8.3 ± 11.3 years, respectively (for detailed subject descriptions, see Table 3.12 in Appendix A). Ethical approval for the study was granted by the Karolinska Institutet (Sweden) Regional Ethics committee and written informed consent was obtained from all the participants.

3.2.2. Experimental Procedure

All amputees participated in the same pre- and post- assessments. The control group continued with the same form and amount of exercise they had been doing regularly for the three months prior to study participation, and had their post-test assessment 10 weeks after their pre-test assessments. Meanwhile, the training group went on to complete 10 weeks of the training program described in [27], and their post-training assessment was performed within two days of completing the training.

Testing consisted of isokinetic muscle testing, overground walking trials, and oxygen consumption treadmill walking trials performed at the same speed as the overground trials. Three-dimensional motion capture was used during the over ground walking trials (ProReflex, Qualysis, Sweden), sampled at 240 Hz. Twenty-three reflective markers were placed on the body, with the markers on the prosthetic limb placed to correspond with the markers on the intact limb (Figure 3.1). Ground reaction forces were captured using an AMTI force platform (Watertown, MA, USA), embedded in a walkway and sampled at 240 Hz. Individuals wore tennis shoes for the trial, and the same prosthesis was worn in both the pre- and post-assessments. Walking trials were repeated as necessary to get two good force plate recordings for both the intact and prosthetic limb, and subjects were asked to walk at approximately 1 m/s. Subjects were allowed to rest between trials if they were fatigued. Muscle testing scores and oxygen consumption values were recorded prior to gait trials, but will not be presented in this study [27].

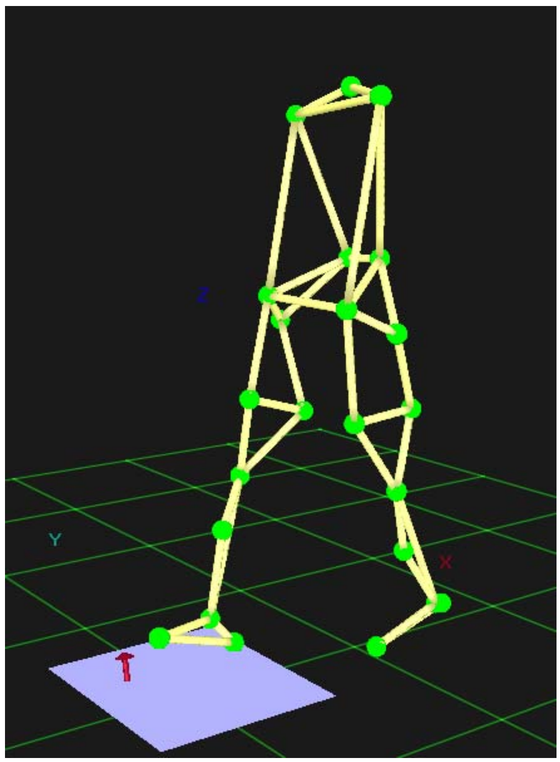

Figure 3.1: *Qualysis Bone Model showing the positions of the twenty-three reflective markers.*

During the pre-testing session, all participants were asked if they could run with their prosthetic limb, and if answered in the affirmative or were not sure, were asked to demonstrate. The ability to run was defined as continuous leg-over-leg running for at least ten seconds on the treadmill at a speed faster than the subject could walk. Only one member of the training group stated he was able to run previously, but upon demonstration was only able to run leg-over-leg for less than three consecutive strides. Running ability was qualitatively assessed in the training group during the post-training assessment period using the same criteria. Those that wished to attempt running were strapped into a harness over a treadmill (Rodby, Vänge, Sweden), and instructed in a leg-over-leg running technique [28]. The treadmill speed was slowly increased until the subject was forced to change from walking to slow jogging. They were allowed to stop and rest at any point if they felt fatigued. All running was attempted with the participant's prosthesis set up for walking.

3.2.3. Data Analysis

3.2.3.1. Spatiotemporal Gait Characteristics

The kinematic data were first analyzed by looking at standard temporal-spatial gait characteristics. These metrics included stride length and time, step length, time and width, stance time and swing time. Ten partially consecutive gait cycles for both the prosthetic and intact limb were randomly chosen from the available kinematic data. Because the force plate only captured one heel strike on one side of the body per trial, marker data were used to find subsequent heel strike and toe-off locations. Heel strike and toe-off locations were validated using force plate data, and it was determined that there was a constant offset for each subject caused by the compression of the sole of the shoe. This offset was taken into account when determining gait events (Table 3.12 in Appendix B).

Initially, the results were separated by group, type, side, and session (Table 3.1). Stride and step length were normalized to subject height. Symmetry index (SI) values were also calculated for each of the spatiotemporal characteristics using the expression [29]:

$$SI = \frac{I - P}{0.5 * (I + P)} * 100 \quad (1)$$

where I was the intact limb parameter and P was the prosthetic limb parameter. Negative SI values indicated that the parameter value for the prosthetic limb was greater than the intact limb.

To gain more insight into the effect of the hip strengthening program, the outcome metrics described above were also separated by the ability of the subjects to run after training.

3.2.3.2. Kinematic Profiles

The kinematic profiles of the hip and pelvis were also investigated. Because amputees have displayed out-of-plane movement of the torso and pelvis [1, 2, 4], it was important not to limit the analysis of the kinematic data to only the sagittal plane. To capture the three-dimensional motion at the hip, OpenSim was chosen as the tool to analyze the experimental data. OpenSim is an open source musculoskeletal modeling program [30], which allows for subject-specific models to be created and analyzed.

A generalized 8-link rigid body model, with 8 joints and 34 degrees of freedom, was first scaled to match experimental motion capture data. Inverse kinematics (joint angles and positions) were determined by solving a least-squares problem at each frame. This least-squares problem minimized the difference between the measured marker location and the model's virtual marker locations, as restricted to joint constraints. Ranges of motion (ROM) were calculated for the hip, pelvis, and torso, and separated in the same manner as the spatiotemporal characteristics (testing session, testing group, prosthesis type, limb side, and running ability). Hip ROM was determined by hip flexion, and pelvis ROM was calculated by the vertical height of the pelvic center of mass. Symmetry indices for the hip flexion ROM were also calculated.

3.2.3.3. Piecewise Linear Length Normalization

The final analysis tool used on this data set was piecewise linear length normalization (PLLN). PLLN is a technique for segmenting gait data into subphases at points of interest and temporally aligning these points of interest for each test trajectory with the corresponding trajectory of the target point of interest [31]. For this data set, the points of interest were clinically relevant gait events, each defining boundaries for specific subphases of gait (see Chapter 2). Here, five sub-phases of gait were determined from six gait events [32]. Loading response was defined as ipsilateral heel strike to contralateral limb toe-off. Mid-stance was defined as contralateral toe-off to weight alignment over the forefoot, which occurred when the center of mass of the torso was aligned with the joint center of the ipsilateral toes. Terminal stance lasted from weight alignment until contralateral heel strike. This gait event began pre-swing, which lasted until ipsilateral toe-off. Swing then continued until the subsequent ipsilateral heel strike. Once the average timings for each of the clinically relevant gait events were determined for each subject during both pre- and post- training, the results were grouped in the same manner as the spatiotemporal and kinematic results. The average timings for the different groups were then determined.

3.2.3.4. Statistical Analysis

The major groupings analyzed were as follows: 1) testing group (training vs. control), 2) prosthesis type (TT or TF), 3) side (prosthetic or intact), 4) testing session (pre- vs. post), and 5) running ability (runner vs. non-runner). Statistical analyses were done as a Student's unpaired or paired t-tests, with significance defined as $p<0.05$. Trends in the data were defined as $0.05 \leq p < 0.10$. All statistical tests were performed in Excel.

3.3. RESULTS

3.3.1. Spatiotemporal Gait Characteristics

3.3.1.1. Results from the Training and Control Groups

Preliminary unpaired t-tests between training and control groups and within limb side found modest differences due in spatiotemporal gait parameters (Tables C.3a and C.3b in Appendix C). For the intact limb of TF subjects (Table C.3a), only average stance time differed significantly between groups and this was only at the start of the study (69.3 ± 0.9 % gait cycle (%GC) for controls and 67.4 ± 1.5 %GC for training, $p = 0.03$). Also during pre-test, average step width tended to be larger for controls (0.17 ± 0.02 m) than training (0.13 ± 0.06m), $p = 0.08$. For the prosthetic limb, there were more differences between training and control group gait parameters for TF subjects than TT subjects (Table C.3b). During pre-test, average step length ($p = 0.01$) and average stance time ($p = 0.03$) were significantly longer for TF training group subjects. These trends tended to remain post-training. Average step time tended to be shorter for the TF training group (0.66 ± 0.02s vs. 0.71 ± 0.04s, $p = 0.07$), but step time increased in the TF training group after training while there was no change for the control group (0.69 ± 0.01s vs. 0.71 ±

0.03s). For TT subjects, average step time on the prosthetic limb also tended to be longer for the TT training group before pre-test ($p = 0.07$) and this difference became significantly different post-test ($p = 0.01$); however, the statistical significance was mainly a result of smaller variance around the mean.

Subsequent analyses were done by separately examining training from control group data. Results from paired t-tests between pre- and post-testing for each group and type found several significant differences in the standard metrics when the data were examined by limb, prosthesis type, and within a test group (Table 3.1, $p<0.05$). Specifically, the TT control group showed a 3% decrease in step length on the prosthetic side in the post-trials as compared to the pre-trials, while the TT training group showed a 3% increase in intact side stride length and 20% increase in intact limb step width post-training. Meanwhile, the TF training group took 5% greater stride time on their prosthetic side. There were some trends present in the data set, as well ($0.05 \leq p < 0.10$). The TT controls tended to spend 2% longer in stance and 2% shorter in swing on their intact side in the post-assessments, while the TF controls took 6% longer steps on their intact limb. In the training group, the TTs had a tendency to increase step time, by 3%, while the TFs had a 2% longer stride time in the post-training sessions versus the pre-training.

Table 3.1: *Table comparing spatiotemporal characteristics of group, type, side, and session. Described are mean values for normalized stride length, stride time, normalized step length, step width, stance time (% Gait Cycle), and swing time (% Gait Cycle) for both the intact (I) and prosthetic (P) sides, with standard deviations.*

Group	Type	Side	Session	Norm. Stride Length (m)	Avg Stride Time (s)	Norm. Step Length (m)	Avg Step Time (s)	Avg Step Width (m)	Avg Stance Time (%GC)	Avg Swing Time (%GC)
Controls	TT	I	Pre	0.72 (0.06)	1.19 (0.07)	0.34 (0.04)	0.60 (0.04)	0.11(0.01)	65.2 (0.9)	34.8 (0.9)
			Post	0.72 (0.05)	1.22 (0.08)	0.35 (0.02)	0.60 (0.06)	0.10 (0.03)	66.0 (1.6)	34.1 (1.6)
		P	Pre	0.72 (0.06)	1.20 (0.06)	0.39 (0.02)	0.60 (0.05)	0.11 (0.02)	63.7 (0.9)	36.3 (0.9)
			Post	0.71 (0.04)	1.20 (0.08)	0.38 (0.02)	0.61 (0.02)	0.13 (0.05)	63.1 (2.5)	36.9 (2.5)
	TF	I	Pre	0.71 (0.03)	1.30 (0.10)	0.35 (0.03)	0.59 (0.07)	0.17 (0.02)	69.3 (0.9)	30.7 (0.9)
			Post	0.73 (0.03)	1.29 (0.09)	0.37 (0.03)	0.58 (0.07)	0.16 (0.01)	69.0 (1.1)	31.0 (1.1)
		P	Pre	0.71 (0.03)	1.30 (0.09)	0.37 (0.01)	0.71 (0.04)	0.16 (0.03)	62.4 (1.9)	37.6 (1.9)
			Post	0.73 (0.03)	1.29 (0.09)	0.36 (0.02)	0.71 (0.03)	0.16 (0.02)	61.2 (2.4)	38.8 (2.4)
Training	TT	I	Pre	0.67 (0.09)	1.26 (0.13)	0.34 (0.04)	0.59 (0.10)	0.10 (0.03)	68.4 (4.2)	31.6 (4.2)
			Post	0.69 (0.09)	1.26 (0.10)	0.35 (0.03)	0.60 (0.10)	0.12 (0.04)	67.8 (3.4)	32.2 (3.4)
		P	Pre	0.68 (0.09)	1.25 (0.14)	0.33 (0.05)	0.66 (0.04)	0.13 (0.03)	62.43 (2.8)	37.6 (2.8)
			Post	0.69 (0.09)	1.26 (0.09)	0.34 (0.06)	0.66 (0.01)	0.10 (0.05)	63.1 (3.1)	36.9 (3.1)
	TF	I	Pre	0.70 (0.06)	1.28 (0.08)	0.32 (0.04)	0.62 (0.06)	0.13 (0.06)	67.4 (1.5)	32.6 (1.5)
			Post	0.69 (0.04)	1.32 (0.05)	0.32 (0.05)	0.62 (0.03)	0.13 (0.06)	68.3 (0.9)	31.7 (0.9)
		P	Pre	0.69 (0.05)	1.26 (0.08)	0.37 (0.02)	0.66 (0.02)	0.14 (0.05)	65.2 (1.4)	34.8 (1.4)
			Post	0.70 (0.05)	1.29 (0.05)	0.38 (0.01)	0.69 (0.01)	0.13 (0.05)	64.0 (2.6)	36.0 (2.6)

Pink cells indicate significant differences between pre and post-test and within a test group, prosthesis type, and limb side using a paired t-test (p<0.05), while orange cells indicate borderline significance between pre and post (0.05≤ p <0.1)

The symmetry index (SI) values for certain standard gait metrics were found to significantly change (p<0.05) between pre- and post-testing for all control subjects, while borderline significant trends (0.05≤p<0.10) were observed in the training group (Table 3.2). For the control group, statistically significant changes in the directionality of movement symmetry were noted for stride time and step width (pink shading, p<0.05). Specifically, TT controls changed from longer stride times on the prosthetic side during the pre-trials to longer stride times on the intact side after 10 weeks. TF controls used greater step widths on the intact side at baseline and greater widths with the prosthetic side after 10 weeks. The TT training group, on the other hand, showed an opposite borderline significant trend such that the asymmetry in step width changed from wider steps on the prosthetic side before training to wider steps on the intact side after training (orange shading, 0.05≤ p <0.10). Training also seemed to reduce the asymmetry in step width for TF subjects. Further, control subjects showed trends toward more symmetrical step lengths over time, while TT training subjects showed an increasing trend in symmetry in both stance and swing time.

Table 3.2: *Symmetry index values for standard metrics, separated by group, type, and session.*

AVERAGE SYMMETRY INDEX VALUES FOR STANDARD METRICS									
			Norm. Stride Length	Avg Stride Time	Norm. Step Length	Avg Step Time	Avg Step Width	Avg Stance Time	Avg Swing Time
Controls	TT	Pre	0.22	-0.78	-13.68	-1.32	-1.95	2.39	-4.34
		Post	1.30	1.07	-7.81	-3.20	-23.14	4.48	-8.01
	TF	Pre	-0.23	0.60	-5.56	-18.40	9.31	10.57	-20.21
		Post	0.10	-0.04	0.68	-19.83	-5.14	11.92	-22.03
Training	TT	Pre	-0.59	0.30	3.75	-12.04	-29.34	9.07	-17.69
		Post	0.03	0.08	2.38	-10.19	17.97	7.12	-13.59
	TF	Pre	1.80	1.24	-14.37	-6.68	-12.02	3.35	-6.59
		Post	-0.36	1.83	-15.55	-10.79	-5.07	6.47	-12.39

Negative SI values indicate that the prosthetic limb value was greater than for the intact limb. Pink cells indicate significant differences between pre- and post ($p<0.5$), while orange cells indicate borderline significance between pre- and post- ($0.05 \leq p < 0.1$).

3.3.1.2. Runners vs. Non-runners Comparison

Because an additional aim of the study was to determine if the training program was suitable to develop sufficient strength to enable running, the data were separated by ability to run after training (Table 3.3). Of the seven members of the training group (4 TT, 3 TF), only one TT subject was unable to run after training. By separating the data in this manner, other significant differences in overall kinematic behavior pre- and post-training became apparent. On average for the non-runners, step length increased by 3% on the intact limb; while on the prosthetic limb, swing time increased and stance time decreased by 3%. In the runners, average step width increased by 19% on the intact side in the post-trials as compared to the pre-trials. Symmetry index values were also calculated between the limbs for this grouping, but they showed no significant or border-line significant trends (Table 3.4).

Table 3.3: *Table comparing spatiotemporal characteristics of running condition, side, and session. Described are normalized stride length (m), stride time (s), normalized step length (m), step width (m), stance time (% Gait Cycle), and swing time (% Gait Cycle) for both the intact (I) and prosthetic (P) sides, with standard deviations.*

			Norm Stride Length (m)	Avg Stride Time (s)	Norm Step Length (m)	Avg Step Time (s)	Avg Step Width (m)	Avg Stance Time (%GC)	Avg Swing Time (%GC)
Non- Runners	I	Pre	0.70 (0.07)	1.25 (0.10)	0.34 (0.03)	0.58 (0.07)	0.14 (0.04)	68.3 (2.7)	31.7 (2.7)
		Post	0.71 (0.07)	1.25 (0.09)	0.35 (0.03)	0.58 (0.07)	0.13 (0.04)	68.2 (2.1)	31.8 (2.1)
	P	Pre	0.70 (0.07)	1.24 (0.10)	0.36 (0.04)	0.67 (0.06)	0.14 (0.03)	62.6 (1.7)	37.4 (1.7)
		Post	0.70 (0.06)	1.25 (0.09)	0.36 (0.04)	0.67 (0.05)	0.14 (0.05)	61.6 (2.5)	38.4 (2.5)
Runners	I	Pre	0.71 (0.04)	1.29 (0.10)	0.34 (0.04)	0.62 (0.07)	0.11 (0.05)	67.2 (2.6)	32.8 (2.6)
		Post	0.71 (0.04)	1.30 (0.07)	0.34 (0.04)	0.63 (0.06)	0.13 (0.05)	67.5 (2.4)	32.5 (2.4)
	P	Pre	0.70 (0.04)	1.28 (0.10)	0.37 (0.02)	0.67 (0.03)	0.13 (0.04)	64.1 (2.4)	35.9 (2.4)
		Post	0.71 (0.04)	1.29 (0.06)	0.37 (0.02)	0.68 (0.02)	0.12 (0.04)	64.2 (2.1)	35.8 (2.1)

Pink cells indicate significant differences between pre- and post ($p<0.5$).

Table 3.4: *Symmetry index values for standard metrics, separated by running condition and session.*

AVERAGE SYMMETRY INDEX VALUES FOR STANDARD METRICS								
		Norm. Stride	Avg Stride Time (s)	Norm. Step	Avg Step Time (s)	Avg Step Width (m)	Avg Stance	Avg Swing Time
Non- Runners	Pre	-0.07	0.15	-6.33	-13.67	-1.48	8.69	-16.72
	Post	0.46	0.28	-0.38	-14.89	-5.17	10.09	-18.58
Runners	Pre	0.52	0.71	-6.67	-6.85	-16.57	4.68	-9.02
	Post	-0.12	1.04	-8.96	-7.98	1.34	5.02	-9.75

Prior to the training period, no subject was able to run on the treadmill. After training, all but one subject of the training group was able to run continuously for ten seconds on the treadmill. This one subject's spatiotemporal behaviors were very different from the others who could run (see Table C.6 in Appendix C). The normalized stride lengths of both limbs of this subject fell three standard deviations (SD) outside the mean range of the runners, while stride time for both limbs was outside by one SD. Interestingly, while the normalized step length of the intact limb fell within the range of the runners, the prosthetic limb step length of this subject was shorter by five SDs. Other interesting trends in this subject as compared to the runners was that while the intact limb became more like the runners in stance and swing (from two SD outside of the norm during baseline to one SD outside post training) in the post trials, the prosthetic limb became less similar (i.e., one SD pre-test to two SD post-test) in both parameters.

3.3.2. Kinematic Profiles

3.3.2.1. Results from the Training and Control Groups

The hip flexion range of motion comparing group, type, side and session can be seen in Table 3.5. The intact side hip flexion ROM of the TF control group increased by 18%, while the prosthetic side hip flexion of the TF training group showed a tendency to increase their hip flexion by 8%. Symmetry indices showed no significant differences between sessions in either of the groups or types. The pelvic COM range of motion results are given in Table 3.6. In the first grouping, there was a significant decrease of 15% in the TT control pelvic motion, while there was an increase of 9% in the pelvic COM motion of the TF training group.

Table 3.5: *Comparison the hip flexion range of motion, in degrees (with standard deviation), with group, type, side and session.*

HIP FLEXION RANGE OF MOTION (DEGREES)				
Controls	TT	I	Pre	40.1 (3.1)
			Post	40.7 (6.8)
		P	Pre	39.9 (8.1)
			Post	40.9 (7.8)
	TF	I	Pre	38.7 (6.7)
			Post	47.3 (4.6)
		P	Pre	42.5 (3.0)
			Post	40.8 (5.8)
Training	TT	I	Pre	40.5 (2.1)
			Post	43.5 (4.0)
		P	Pre	40.4 (9.8)
			Post	42.0 (7.0)
	TF	I	Pre	43.9 (7.9)
			Post	48.7 (3.3)
		P	Pre	36.1 (6.4)
			Post	39.4 (8.9)

Pink cells indicate significant differences between pre and post ($p<0.05$), while orange cells indicate borderline significance between pre and post ($0.05 \leq p < 0.1$)

Table 3.6: *Pelvic COM Range of Motion, arranged by group, type, and session.*

PELVIS COM RANGE OF MOTION (m)			
Controls	TT	Pre	0.047 (0.004)
		Post	0.041 (0.002)
	TF	Pre	0.056 (0.010)
		Post	0.060 (0.008)
Training	TT	Pre	0.049 (0.003)
		Post	0.047 (0.005)
	TF	Pre	0.050 (0.005)
		Post	0.055 (0.001)

Pink cells indicate significant differences between pre and post ($p<0.05$), while orange cells indicate borderline significance between pre and post ($0.05 \leq p < 0.1$)

3.3.2.2. Runners vs. Non-runners Comparison

When the hip flexion ROM was separated by running capability (Table 3.7), the only significant change occurred in the non-runners, with an 11% increase in the ROM of their intact limb. The running group showed an increased trend of 9% and 4% for the intact and prosthetic limbs, respectively. Comparing the hip flexion of the single non-runner in the training group to the remainder of the runners, the intact side hip flexion in the post training trials and the prosthetic side hip flexion during both assessments fell 1SD outside of the running group averages (see Table D.4 in Appendix D).

Table 3.7: *Table comparing the hip flexion range of motion, in degrees with running condition, side, and session (with standard deviations).*

HIP FLEXION RANGE OF MOTION (DEGREES)			
Non- Runners	I	Pre	39.3 (5.0)
		Post	44.5 (5.8)
	P	Pre	39.9 (6.7)
		Post	39.9 (6.3)
Runners	I	Pre	42.3 (5.6)
		Post	46.4 (4.4)
	P	Pre	40.5 (7.0)
		Post	42.3 (6.8)

Pink cells indicate significant differences between pre and post ($p<0.05$), while orange cells indicate borderline significance between pre and post ($0.05 \leq p < 0.1$)

Separating the groups into runners vs. non-runners showed no significant differences in the pelvic COM ROM between conditions (Table 3.8). The single non-runner of the training group had a pelvic COM motion that in the pre-trials fell 1 SD outside of the runners, while in the post-training trials fell within the normal range (see Table 3.24 in Appendix D).

Table 3.8: *Tables with pelvis COM locations, in meters (standard deviations), with (1) group, type, side, and session, and (2) running condition, side, and session.*

PELVIS COM RANGE OF MOTION (m)		
Non-Runners	Pre	0.052 (0.009)
	Post	0.052 (0.011)
Runners	Pre	0.050 (0.003)
	Post	0.051 (0.006)

3.3.3. Piecewise Linear Length Normalization

3.3.3.1. Results from the Training and Control Groups

PLLN showed several significant differences pre- and post- training in only the control group; there was no change in the gait event timings in the training group (Table 3.9). Significant differences included a 4% decrease in the amount of time spent in swing for the TT controls, and a 5% decrease in the amount of time spent in pre-swing in the TF controls, both on the intact limb. In terms of borderline significant changes, there was a 4% increase in the amount of time spent in loading response on the prosthetic side of the TT controls, and a 3% increase in the amount of prosthetic swing on the TF controls.

Table 3.9: *Timings of the subphases of gait as determined by PLLN. Data are arranged according to group, type, side, and session. All timing values are averages given in % gait cycle (with standard deviation).*

PLLN SUBPHASE TIMINGS (IN % GAIT CYCLE)								
				Loading Response	Mid-Stance	Terminal Stance	Pre-Swing	Swing
Control	TT	I	Pre	13.7 (0.6)	17.3 (1.5)	19.7 (2.1)	14.3 (1.5)	35.0 (1.0)
			Post	14.0 (1.0)	19.3 (3.1)	17.7 (3.2)	15.3 (1.5)	33.7 (1.5)
		P	Pre	14.7 (1.2)	18.7 (0.6)	16.7 (0.6)	14.0 (1.0)	36.0 (1.0)
			Post	15.3 (1.5)	19.0 (3.5)	15.0 (2.0)	13.7 (0.6)	37.0 (2.6)
	TF	I	Pre	17.0 (3.0)	18.6 (6.2)	19.4 (5.9)	14.6 (2.2)	30.6 (0.5)
			Post	16.0 (3.2)	19.0 (3.3)	20.2 (3.5)	13.8 (2.6)	31.0 (1.0)
		P	Pre	14.4 (2.5)	17.8 (4.0)	13.0 (5.4)	17.0 (3.0)	37.8 (1.9)
			Post	13.8 (2.6)	17.2 (4.3)	14.0 (4.7)	16.2 (2.9)	38.8 (2.4)
Training	TT	I	Pre	15.8 (3.2)	18.3 (3.8)	19.3 (1.0)	15.3 (2.9)	31.5 (4.2)
			Post	15.5 (3.7)	17.8 (3.9)	19.8 (2.5)	15.0 (0.8)	32.0 (3.6)
		P	Pre	15.0 (2.2)	16.8 (2.2)	15.3 (3.3)	15.8 (3.4)	37.3 (2.9)
			Post	15.3 (1.3)	17.3 (3.6)	15.0 (2.6)	15.5 (3.7)	37.0 (3.4)
	TF	I	Pre	16.0 (2.6)	18.7 (1.5)	17.3 (2.9)	15.3 (1.5)	32.7 (1.2)
			Post	16.3 (1.2)	17.7 (1.5)	18.3 (2.9)	16.0 (1.7)	31.7 (0.6)
		P	Pre	16.0 (2.0)	22.0 (4.4)	11.3 (5.5)	16.3 (3.1)	34.7 (1.5)
			Post	15.7 (1.2)	20.0 (5.2)	12.0 (4.4)	16.3 (2.1)	36.0 (2.6)

Pink cells indicate significant differences between pre and post ($p<0.05$), while orange cells indicate borderline significance between pre and post ($0.05 \le p < 0.1$)

3.3.3.2 Runners vs. non-runners Comparison

In the grouping by running ability, the only significant difference occurred in the prosthetic side swing phase (Table 3.10). The non-runners spent 3% more time in swing on their prosthetic limb in the post trials.

Table 3.10: *Average timing lengths (with standard deviation) of the five subphases of gait as determined by PLLN. Data are arranged according to running condition, side, and session. All timing values are given in % gait cycle.*

			Loading Response	Mid-Stance	Terminal Stance	Pre-Swing	Swing
Non-Runners	I	Pre	15.9 (2.7)	18.7 (4.8)	19.3 (4.4)	14.6 (1.7)	31.7 (2.8)
		Post	15.3 (2.5)	19.4 (3.0)	19.2 (3.2)	14.3 (2.1)	31.7 (1.9)
	P	Pre	14.6 (1.9)	17.9 (3.0)	14.2 (4.3)	16.0 (2.6)	37.3 (1.8)
		Post	14.3 (2.1)	17.6 (3.7)	14.3 (3.5)	15.3 (2.4)	38.4 (2.5)
Runners	I	Pre	15.7 (2.9)	17.7 (2.2)	18.5 (2.3)	15.3 (2.4)	32.8 (2.4)
		Post	15.8 (3.0)	17.0 (2.4)	19.2 (2.8)	15.7 (1.2)	32.3 (2.4)
	P	Pre	15.5 (2.2)	19.5 (4.2)	13.7 (4.9)	15.8 (3.3)	35.7 (2.5)
		Post	15.7 (1.0)	19.0 (4.3)	13.7 (3.8)	15.8 (3.2)	35.8 (2.3)

Pink cells indicate significant differences between pre and post ($p<0.05$), while orange cells indicate borderline significance between pre and post ($0.05 \le p < 0.1$)

The PLLN results from the single non-runner of the training group had several differences when compared to those who could run (see Table E.3 in Appendix E). The length of the loading response on the prosthetic limb decreased in the post training assessment. This change in timing also resulted in the non-runner taking spending less time in load than the runners by 1 SD. The length of mid-stance on the intact limb also remained longer than the runners' normal average by 2 SD in both the pre- and post-assessments. Pre-swing on the intact limb became shorter, which moved the result from inside the range to 1 SD outside the normal. The intact side swing average moved from 2 SDs outside of the normal range to 1, while the prosthetic side stayed 2 SDs outside of the normal runner range.

3.4. DISCUSSION

While the hip strengthening program did result in an improvement in hip strength and reduction in oxygen consumption for all members of the training group, these positive changes did not manifest in kinematic behaviors observed during walking. However, this trend is similar to findings in similar programs done on other populations [24, 33]. In a study by Milot et al., it was observed that while the strength of the hemiparetic limb plantarflexors and hip extensors increased dramatically after training, the participants did not change their habitual gait pattern, as seen in their kinematic and kinetic gait variables [24]. However, these subjects did show an increase in gait speed. In a similar manner, Ouelette et al. showed an improvement in strength, but no significant difference between the intervention and control groups for any performance-based measure [33]. It had been suggested that by combining goal-oriented exercise with strength training, the outcome might have been different. This agreed with the findings by Sjödhal et al., which combined psychological and physiotherapeutic training in a special gait re-education program [34]. This study showed an improvement in gait symmetry and body weight distribution in lower-limb amputees, but suggested that in order to improve amputee gait, it was necessary to re-train the amputees how to walk, not simply strengthen their limbs. Because our study only emphasized strength training, it is probable that when the amputees walked, they maintained their learned gait behaviors.

Although no significant spatiotemporal differences were observed in the training group, the hip strengthening program did successfully enable six of the seven training subjects to run. A study by Czerniecki and Gitter indicated that the hip-flexors and extensors of lower-limb amputee runners experienced significantly more muscle work than equivalent muscles in able-bodied runners, which emphasizes the importance of these muscles to running ability [35]. It is interesting to note that the single non-runner in the training group, while showing similar significant improvements in hip strength as the runners, started out with and ended with weaker hip muscles than the remainder of the group [27]. It is possible that given more time in the training program, this subject would have become strong enough to run. The non-runner also showed significant differences from the group in terms of kinematic behaviors (Table C.6 in Appendix C). This subject displayed shorter stride lengths for both limbs in the pre- and post-training assessments, as well as shorter prosthetic limb step length. The weakened hip flexors also manifested in the sagittal plane hip movement; hip flexion on the prosthetic side was significantly less than the remainder of the runners.

Even though there were no directly significant changes in the training group pre- and post- training trials, there were some interesting trends found in the control group. The TT control group took 3% shorter step lengths on the prosthetic side in the post trials as compared to the pre-testing assessment, as well as longer stance times and shorter swing times on their intact limb (Table 3.1), which is an undesirable trend which can cause loading asymmetries [18-20]. These trends also followed in the comparison of runners versus non-runners (Table 3.3). The results from the TF controls showed a trend towards a larger hip flexion on the intact side in the post-training trials, which indicated a stretching behavior in the intact limb. It has been observed that in order to increase walking speed, lower-limb amputees take longer strides, rather than increasing step frequency [4]. Therefore, it seems likely that in order to maintain the walking speed of 1 m/s, the TF subjects adopted a compensatory strategy in their intact leg. The fact that these metabolically and physiologically undesirable trends are occurring in the control group may indicate that while the training group did not necessarily show improvements in gait behavior, training prevented gait deterioration.

Two key limitations of the current study may provide explanations for lack of observable changes in the training group kinematics. The current study focused on strengthening the hip flexors and extensors; however others have found that increased hip abductor strength correlates strongly with increased weight bearing on the prosthetic limb and improved gait parameters, as well as decreased pelvic tilt and out-of-plane movement of the torso [2, 7, 10]. Future work should investigate if strengthening not only the hip flexors and extensors, but also the hip abductors, will allow kinematic differences to be observed. Another possible explanation for not finding statistical differences in the training group is the enforced 1m/s walking speed. Several studies have suggested that an increase in walking speed indicates an improvement in gait performance [14, 23-25], and it has long been acknowledged that changes in walking speed result in significant gait behavior changes in lower-limb amputees [2, 4, 8]. By having no data to validate the comfortable walking speed of each of the subjects, it was impossible to determine if the subjects were walking faster or slower than their desired pace, which would in turn affect gait behaviors.

There were several other limitations to the study. One limitation was the inability to perform inverse dynamics on this data set. Although efforts were made to determine anthropometric characteristics of each prosthesis, there was a lack of information about the interface between the residual limb and prosthesis socket, which prevented further determination of the mass moments of inertia needed for inverse dynamics calculations. Future work should also examine the effect of the length of intervention. Perhaps given time, the one non-runner in the training group would develop sufficient strength to run. Another limitation was the variety of prosthesis types and levels of amputations, which resulted in small sample sizes when analyzing the data by amputation level and testing group. Both have been found to affect gait kinematics, and could explain why average group values showed no significant changes in the comparison between pre- and post-testing assessments.

We posit the following theory for why negligible changes in walking gait kinematics were observed in the training group post-intervention. The training program was targeted for improving physical performance with the ultimate goal of affording running ability. The initial analysis of this project found significant differences among the training group pre- and post-training in hip strength, metabolic energy expenditure and the ability to run. In the current study, however, we were unable to detect changes in walking gait biomechanics in this group. Walking ability is developed before running ability. Walking may be a less challenging or a simpler task to the neuromuscular system than running. Therefore, for this 10 week intervention that targeted running and not walking retraining, walking gait behavior may not have also been modified. Future work should also investigate existing literature as to whether this difference between observing no changes during simple tasks but documented changes during more complex tasks has been found in other populations.

3.5. CONCLUSION

This study was conducted to determine the plausibility of using a hip strength improving program to improve kinematic performance during walking and determine if the training was sufficient to enable running in lower-limb amputees. While there were no significant changes in kinematic behaviors for the training group in the pre- and post- training assessments, six of the seven training members were able to run after training. The control group, however, demonstrated several significant changes in gait behavior after ten weeks which indicated gait deterioration in this population, even though many of them continued their normal exercise regimes. This reemphasizes the need for constant strength training to prevent muscle atrophy in the residual limb, as well as suggesting that strengthening the hip muscles may have prevented similar trends from occurring in the training group.

3.6. LIST OF REFERENCES

1. Bae, T.S., K. Choi, D. Hong, and M. Mun, *Dynamic analysis of above-knee amputee gait.* Clinical Biomechanics, 2007. **22**(5): p. 557-566.
2. Goujon-Pillet, H., E. Sapin, P. FodÃ©, and F. Lavaste, *Three-Dimensional Motions of Trunk and Pelvis During Transfemoral Amputee Gait.* Archives of Physical Medicine and Rehabilitation, 2008. **89**(1): p. 87-94.
3. Isakov, E., O. Keren, and N. Benjuya, *Trans-tibial amputee gait: Time-distance parameters and EMG activity.* Prosthetics and Orthotics International, 2000. **24**(3): p. 216-220.
4. Jaegers, S.M.H.J., J.H. Arendzen, and H.J. De Jongh, *Prosthetic gait of unilateral transfemoral amputees: A kinematic study.* Archives of Physical Medicine and Rehabilitation, 1995. **76**(8): p. 736-743.
5. Kovac, I., V. Medved, and L. Ostojic, *Spatial, temporal and kinematic characteristics of traumatic transtibial amputees' gait.* Collegium Antropologicum. **34**(SUPPL. 1): p. 205-213.
6. Su, P.F., S.A. Gard, R.D. Lipschutz, and T.A. Kuiken, *Gait characteristics of persons with bilateral transtibial amputations.* Journal of Rehabilitation Research and Development, 2007. **44**(4): p. 491-501.
7. Nadollek, H., S. Brauer, and R. Isles, *Outcomes after trans-tibial amputation: the relationship between quiet stance ability, strength of hip abductor muscles and gait.* Physiotherapy research international : the journal for researchers and clinicians in physical therapy, 2002. **7**(4): p. 203-214.
8. Nolan, L., A. Wit, K. DudziÃ±ski, A. Lees, M. Lake, and M. WychowaÃ±ski, *Adjustments in gait symmetry with walking speed in trans-femoral and trans-tibial amputees.* Gait and Posture, 2003. **17**(2): p. 142-151.
9. Radin, E.L., H.G. Parker, J.W. Pugh, R.S. Steinberg, I.L. Paul, and R.M. Rose, *Response of joints to impact loading -- III: Relationship between trabecular microfractures and cartilage degeneration.* Journal of Biomechanics, 1973. **6**(1): p. 51-54, IN9-IN11, 55-57.
10. Renstrom, P.A.F.H., H. Alaranta, and T. Pohjolainen, *Review: Leg strengthening of the lower limb amputee.* Critical Reviews in Physical and Rehabilitation Medicine, 1995. **7**(1): p. 11-32.
11. Schmalz, T., S. Blumentritt, and R. Jarasch, *Energy expenditure and biomechanical characteristics of lower limb amputee gait:: The influence of prosthetic alignment and different prosthetic components.* Gait & Posture, 2002. **16**(3): p. 255-263.
12. Waters, R.L. and S. Mulroy, *The energy expenditure of normal and pathologic gait.* Gait and Posture, 1999. **9**(3): p. 207-231.

13. Isakov, E., H. Burger, M. Gregoria, and C. Marinaek, *Isokinetic and isometric strength of the thigh muscles in below-knee amputees.* Clinical Biomechanics, 1996. **11**(4): p. 233-235.
14. Klingenstierna, U., P. Renstrom, G. Grimby, and B. Morelli, *Isokinetic strength training in below-knee amputees.* Scandinavian Journal of Rehabilitation Medicine, 1990. **22**(1): p. 39-43.
15. Renstrom, P., G. Grimby, and E. Larsson, *Thigh muscle strength in below-knee amputees.* Scandinavian Journal of Rehabilitation Medicine, 1983. **15**(SUPPL.9): p. 163-173.
16. Renstrom, P., G. Grimby, B. Morelli, and B. Palmertz, *Thigh muscle atrophy in below-knee amputees.* Scandinavian Journal of Rehabilitation Medicine, 1983. **15**(SUPPL.9): p. 150-162.
17. Sherk, V.D., M.G. Bemben, and D.A. Bemben, *Interlimb Muscle and Fat Comparisons in Persons With Lower-Limb Amputation.* Archives of Physical Medicine and Rehabilitation. **91**(7): p. 1077-1081.
18. Burke, M.J., V. Roman, and V. Wright, *Bone and joint changes in lower limb amputees.* Annals of the Rheumatic Diseases, 1978. **37**(3): p. 252-254.
19. Kulkarni, J., J. Adams, E. Thomas, and A. Silman, *Association between amputation, arthritis and osteopenia in British male war veterans with major lower limb amputations.* Clinical Rehabilitation, 1998. **12**(4): p. 348-353.
20. Lloyd, C.H., S.J. Stanhope, I.S. Davis, and T.D. Royer, *Strength asymmetry and osteoarthritis risk factors in unilateral trans-tibial, amputee gait.* Gait and Posture. **32**(3): p. 296-300.
21. Kegel, B., J.C. Webster, and E.M. Burgess, *Recreational activities of lower extremity amputees: A survey.* Archives of Physical Medicine and Rehabilitation, 1980. **61**(6): p. 258-264.
22. Damiano, D.L., A.S. Arnold, K.M. Steele, and S.L. Delp, *Can strength training predictably improve gait kinematics? A pilot study on the effects of hip and knee extensor strengthening on lower-extremity alignment in cerebral palsy.* Physical Therapy, 2010. **90**(2): p. 269-279.
23. Jorgensen, J.R., D.T. Bech-PÃ¨dersen, P. Zeeman, J. SÃ¸rensen, L.L. Andersen, and M. Schonberger, *Effect of intensive outpatient physical training on gait performance and cardiovascular health in people with hemiparesis after stroke.* Physical Therapy, 2010. **90**(4): p. 527-537.
24. Milot, M.H., S. Nadeau, D. Gravel, and D. Bourbonnais, *Effect of increases in plantarflexor and hip flexor muscle strength on the levels of effort during gait in individuals with hemiparesis.* Clinical Biomechanics, 2008. **23**(4): p. 415-423.
25. Kegel, B., E.M. Burgess, T.W. Starr, and W.K. Daly, *Effects of isometric muscle training on residual limb volume, strength, and gait of below-knee amputees.* Physical Therapy, 1981. **61**(10): p. 1419-1426.
26. Sjodahl, C., G.B. Jarnlo, and B.M. Persson, *Gait improvement in unilateral transfemoral amputees by a combined psychological and physiotherapeutic treatment.* Journal of Rehabilitation Medicine, 2001. **33**(3): p. 114-118.
27. Nolan, L., *A Training Program to Improve Hip Strength in Lower Limb Amputees.* under review.

28. Gailey, R., *Five Steps for the Introduction to Lower Limb Amputee Running.* The O & P Edge, 2003. **2**(12).
29. Becker, H.P., D. Rosenbaum, T. Kriese, H. Gerngross, and L. Claes, *Gait asymmetry following successful surgical treatment of ankle fractures in young adults.* Clinical Orthopaedics and Related Research, 1995(311): p. 262-269.
30. Delp, S.L., F.C. Anderson, A.S. Arnold, P. Loan, A. Habib, C.T. John, E. Guendelman, and D.G. Thelen, *OpenSim: Open-source software to create and analyze dynamic simulations of movement.* IEEE Transactions on Biomedical Engineering, 2007. **54**(11): p. 1940-1950.
31. Helwig, N.E., S. Hong, E.T. Hsiao-Wecksler, and J.D. Polk, *Methods to temporally align gait cycle data.* Journal of Biomechanics.
32. Perry, J., *Gait Analysis*. 1992, Slack, Inc.: Thorofare, NJ. p. 11-15.
33. Ouellette, M.M., N.K. LeBrasseur, J.F. Bean, E. Phillips, J. Stein, W.R. Frontera, and R.A. Fielding, *High-intensity resistance training improves muscle strength, self-reported function, and disability in long-term stroke survivors.* Stroke, 2004. **35**(6): p. 1404-1409.
34. Sjodahl, C., G.B. Jarnlo, B. Soderberg, and B.M. Persson, *Kinematic and kinetic gait analysis in the sagittal plane of trans-femoral amputees before and after special gait re-education.* Prosthetics and Orthotics International, 2002. **26**(2): p. 101-112.
35. Czerniecki, J.M. and A. Gitter, *Insights into amputee running: A muscle work analysis.* American Journal of Physical Medicine and Rehabilitation, 1992. **71**(4): p. 209-218.

CHAPTER 4: CONCLUSIONS

In an effort to improve motor function of lower-limb amputees, it was theorized that a hip strengthening training program would help to improve amputees' kinematic performance. An additional aim of the study was to determine if the training program was sufficient to enable lower-limb amputees to run. Standard spatiotemporal characteristics, kinematic profiles, and gait event timings were all investigated in an attempt to understand the effect of the training on lower-limb amputees.

The development of the piecewise linear length normalization technique (PLLN), utilizing clinically relevant gait events as points of interest, is described in Chapter 2. PLLN is a curve registration technique which linearly compresses or expands the time axis of a test curve to a target data set. Gait events were used as the alignment points of interest on a knee-braced data set. By specifically selecting clinically-relevant gait events, it was possible to provide improved interpretation of gait behaviors, especially those behaviors that deviated from normative patterns. PLLN provided additional insights into gait behavior by giving more detailed information about the temporal shifts in gait patterns, as compared to other normalization techniques. These subtle timing shifts could potentially provide useful information about impaired control mechanisms of gait in other populations, such as stroke patients or lower-limb amputees. By aligning the data using PLLN, it was possible to examine changes in kinematic intensity behaviors at clinically relevant locations, and not just at peaks or valleys, as seen in other techniques.

Due to the advantages given by alignment of data with PLLN, it was chosen as a tool to analyze the amputee data set, along with standard spatiotemporal metrics and kinematic profile analysis. The results from this study showed that while there were no significant changes in kinematic gait behaviors for the training group in the pre- and post- training assessments, there were significant changes in the gait behaviors of the control group. The control group's gait behaviors actually seemed to deteriorate over time, which re-emphasized the need for constant strength training to prevent muscle atrophy in the residual limb. This deterioration also suggested that strengthening the hip muscles may have prevented similar trends from occurring in the training group. Hip strengthening also enabled six of the seven training group members to run, which was one of the aims of the study.

The hip strengthening program showed some promising results. Specifically, the metabolic cost associated with walking decreased, the hip flexor/extensor strength of the training group increased, and all but one member of the training group were able to run. If the study were to be repeated, there are several changes to be made in the protocol. Since the hip abductors play a significant role in the kinematic behaviors of amputees, strengthening of these muscles in addition to the flexors should be considered. Walking trials should not be performed at one set walking speed, but should be tested at a set slow, set fast, and free individual comfortable walking speed. This could potentially eliminate the effects of walking speed on the kinematic results, as well as provide additional insight into the effect of the training on subject speed. An additional limitation of this study was the variety of prostheses and levels of amputation, which resulted in small sample sizes when analyzing the data by amputation level and testing group. Both have been found to affect gait kinematics, and could explain why average group values showed no significant changes in the comparison between pre- and post- testing assessments.

In general, while there were no significant improvements seen in the gait characteristics of the training group, the analysis demonstrated that the hip strengthening program prevented the gait deterioration seen in the control group, and did enable all but one member of the training group to run.

APPENDIX A: PLLN TIMINGS FOR HEALTHY ADULT MALES

Table A.1: *Individual Subject Average Timings for the Un-braced Data Set*

Right Leg (% GC)							
Subject	Loading Response	Mid-Stance	Terminal Stance	Pre-Swing	Initial Swing	Mid-Swing	Terminal Swing
sim001	20	11	20	19	10	14	6
sim002	20	13	18	19	9	14	7
sim003	18	15	18	17	10	15	7
sim004	17	13	19	17	8	16	10
sim005	18	12	20	17	10	16	7
sim006	17	16	15	18	9	17	8
sim007	18	16	16	19	10	16	5
sim008	18	15	15	19	9	14	10
sim009	18	15	19	18	11	16	3
sim010	17	12	20	17	10	15	9
Average	**18.1**	**13.8**	**18.0**	**18.0**	**9.6**	**15.3**	**7.2**
stdev	**1.1**	**1.8**	**2.0**	**0.9**	**0.8**	**1.1**	**2.2**

Left Leg (% GC)							
Subject	Loading Response	Mid-Stance	Terminal Stance	Pre-Swing	Initial Swing	Mid-Swing	Terminal Swing
sim001	19	11	21	20	9	9	11
sim002	19	14	16	20	9	9	13
sim003	17	15	19	18	10	9	12
sim004	17	10	20	17	9	10	17
sim005	17	14	18	18	9	11	13
sim006	18	14	17	17	9	8	17
sim007	19	15	18	18	10	9	11
sim008	20	14	17	18	9	7	15
sim009	18	15	19	18	11	10	9
sim010	17	12	20	17	10	10	14
Average	**18.1**	**13.4**	**18.5**	**18.1**	**9.5**	**9.2**	**13.2**
stdev	**1.1**	**1.8**	**1.6**	**1.1**	**0.7**	**1.1**	**2.6**

Table A.2: *Individual Subject Average Timings for the Braced Data Set*

Right Leg (% GC)							
Subject	Loading Response	Mid-Stance	Terminal Stance	Pre-Swing	Initial Swing	Mid-Swing	Terminal Swing
sim001	16	8	21	16	11	17	11
sim002	15	10	17	6	21	15	16
sim003	15	15	18	17	11	16	8
sim004	15	13	19	17	9	17	10
sim005	15	10	22	16	11	16	10
sim006	15	14	17	17	10	17	10
sim007	13	10	23	16	12	16	10
sim008	13	10	22	16	13	16	10
sim009	14	14	20	18	12	15	7
sim010	14	8	23	16	15	16	8
Average	**14.5**	**11.2**	**20.2**	**15.5**	**12.5**	**16.1**	**10.0**
stdev	**1.0**	**2.6**	**2.3**	**3.4**	**3.4**	**0.7**	**2.4**

Left Leg (% GC)							
Subject	Loading Response	Mid-Stance	Terminal Stance	Pre-Swing	Initial Swing	Mid-Swing	Terminal Swing
sim001	16	14	23	16	9	10	9
sim002	10	23	20	15	7	9	16
sim003	16	15	23	15	11	9	11
sim004	16	14	22	15	9	10	14
sim005	16	15	22	15	8	10	14
sim006	17	14	23	15	10	7	14
sim007	16	12	25	13	9	10	15
sim008	16	14	24	13	8	8	17
sim009	17	13	24	14	11	8	13
sim010	16	15	28	14	9	10	8
Average	**15.6**	**14.9**	**23.4**	**14.5**	**9.1**	**9.1**	**13.1**
stdev	**2.0**	**3.0**	**2.1**	**1.0**	**1.3**	**1.1**	**2.9**

APPENDIX B: AMPUTEE SUBJECT CHARACTERISTICS

Table B.1: *Subject Details of those involved in the hip strengthening program. Offsets in gait events as determined by force plate data are also listed.*

Gender	Amputation Level	Mass (kg)	Height (m)	Age (Years)	Years as an Amputee	Reason for Amputation	Prosthesis (knee, foot)	Group	Exercise/ Week	Exercise Type	Gait Events Offset (Frames)
M	TF	113	1.94	49	1.5	Trauma	Mauch, flex foot	Training	0		-4
M	TF	80.6	1.8	35	8	Trauma	Black max II, flex foot	Training	0		-2
M	TF	66	1.8	38	1	Tumor	Black max II, flex foot	Training	0		-2
F	TT	68	1.65	28	28	Congenital	- flex foot	Training	0		-2
M	TT	68	1.67	54	13	Trauma	- dynamic foot	Training	7	Sit-ups, Push-ups	2
M	TT	133.5	1.97	47	2.5	Trauma	- dynamic foot	Training	1	Physiotherapy	-4
M	TT	112.8	1.91	40	1.5	Trauma	- dynamic foot	Training	2	Boxing, Water Aerobics	-4
M	TF	76.5	1.78	39	15	Trauma	Mauch, flex foot	Control	0		-8
M	TF	83.8	1.8	53	2.5	Trauma	Mauch, flex foot	Control	1	Physiotherapy	-4
M	TF	101.5	1.89	55	1.5	Trauma	c-leg, dynamic foot	Control	7	Nordic Walking	0
F	TF	67	1.68	58	3	Trauma	Mauch, flex foot	Control	0		-1
F	TF	65	1.64	49	2.5	Trauma	Mauch, flex foot	Control	3	Swimming	-3
M	TT	60	1.7	59	34	Trauma	- flex foot	Control	2	Walking	-2
F	TT	64	1.7	45	2.5	Trauma	- flex foot	Control	2	Gym (aerobics)	-1
M	TT	91.5	1.69	34	5	Trauma	- flex foot	Control	0		-2

APPENDIX C: AMPUTEE SPATIOTEMPORAL CHARACTERISTICS

Table C.1a: *Individual spatiotemporal characteristics of Subject 1*

Subject	Condition	Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)	TTEST
		1.21		1.17		0.63		0.56		0.10		67		33	
		1.22		1.15		0.62		0.53		0.15		69		31	
		1.21		1.14		0.58		0.53		0.15		69		31	
		1.22		1.21		0.60		0.56		0.16		67		33	
	Intact Side Pre	1.18		1.18		0.57		0.54		0.19		69		31	
		1.20		1.18		0.63		0.55		0.15		68		32	
		1.16		1.27		0.57		0.59		0.15		69		31	
		1.17		1.25		0.58		0.56		0.20		71		29	
		1.18		1.23		0.57		0.56		0.17		69		31	
		1.15		1.22		0.55		0.56		0.12		70		30	
	AVERAGE	**1.19**		**1.20**		**0.59**		**0.55**		**0.15**		**69**		**31**	
		1.18		1.17		0.61		0.53		0.14		69		31	
		1.22		1.22		0.62		0.56		0.13		68		32	
		1.21		1.16		0.63		0.56		0.16		68		32	
		1.24		1.24		0.62		0.57		0.15		68		32	
	Intact Side Post	1.19	**0.12**	1.20	**0.85**	0.61	**0.04**	0.58	**0.88**	0.16	**0.85**	67	**0.43**	33	**0.43**
		1.21		1.25		0.61		0.58		0.14		68		32	
		1.17		1.15		0.58		0.53		0.20		70		30	
		1.21		1.17		0.61		0.53		0.18		71		29	
		1.24		1.20		0.63		0.56		0.13		68		32	
		1.24		1.19		0.60		0.53		0.17		69		31	
SUBJECT 1 (TFC)	**AVERAGE**	**1.21**		**1.20**		**0.61**		**0.55**		**0.16**		**69**		**31**	
		1.24		1.18		0.61		0.62		0.12		60		40	
		1.16		1.17		0.56		0.62		0.19		60		40	
		1.24		1.15		0.61		0.63		0.16		59		41	
		1.21		1.20		0.62		0.65		0.10		59		41	
	Prosthetic Side Pre	1.23		1.18		0.60		0.63		0.12		59		41	
		1.22		1.20		0.61		0.65		0.12		60		40	
		1.16		1.28		0.59		0.68		0.12		62		38	
		1.17		1.22		0.60		0.67		0.12		62		38	
		1.16		1.26		0.60		0.68		0.16		61		39	
		1.16		1.23		0.61		0.67		0.14		63		38	
	AVERAGE	**1.19**		**1.21**		**0.60**		**0.65**		**0.13**		**60**		**40**	
		1.19		1.17		0.58		0.64		0.13		58		42	
		1.23		1.20		0.60		0.66		0.14		60		40	
		1.21		1.19		0.58		0.60		0.17		59		41	
		1.22		1.20		0.62		0.68		0.15		61		39	
	Prosthetic Side Post	1.22	**0.29**	1.22	**0.59**	0.61	**0.81**	0.65	**0.93**	0.13	**0.33**	61	**0.28**	39	**0.28**
		1.22		1.24		0.60		0.67		0.14		60		40	
		1.13		1.15		0.55		0.62		0.18		61		39	
		1.21		1.19		0.60		0.66		0.17		59		41	
		1.26		1.21		0.63		0.65		0.11		59		41	
		1.22		1.18		0.63		0.65		0.14		59		41	
	AVERAGE	**1.21**		**1.20**		**0.60**		**0.65**		**0.15**		**60**		**40**	

Table C.1b: *Individual spatiotemporal characteristics of Subject 2*

		Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)	TTEST
SUBJECT 2 (TFC)	Intact Side Pre	1.33		1.31		0.66		0.60		0.16		69		31	
		1.36		1.32		0.72		0.63		0.19		69		31	
		1.33		1.32		0.71		0.61		0.20		69		31	
		1.35		1.27		0.63		0.54		0.20		69		31	
		1.31		1.37		0.63		0.58		0.24		68		32	
		1.33		1.43		0.66		0.65		0.20		68		32	
		1.27		1.41		0.65		0.69		0.26		69		31	
		1.31		1.39		0.66		0.65		0.19		69		31	
		1.31		1.40		0.67		0.68		0.18		68		32	
		1.29		1.35		0.67		0.64		0.17		69		31	
	Average	**1.32**		**1.36**		**0.66**		**0.63**		**0.20**		**69**		**31**	
	Intact Side Post	1.34		1.35		0.68		0.63		0.13		68		32	
		1.35		1.33		0.71		0.61		0.10		69		31	
		1.31		1.38		0.71		0.66		0.17		69		31	
		1.35		1.30		0.71		0.64		0.15		66		34	
		1.31	**0.07**	1.35	**0.53**	0.68	**0.02**	0.66	**0.19**	0.16	**0.00**	69	**0.01**	31	**0.01**
		1.43		1.32		0.70		0.62		0.16		66		34	
		1.43		1.33		0.70		0.62		0.16		66		34	
		1.36		1.44		0.67		0.70		0.11		66		34	
		1.36		1.45		0.68		0.68		0.08		68		32	
		1.30		1.47		0.67		0.70		0.13		67		33	
	Average	**1.36**		**1.37**		**0.69**		**0.65**		**0.14**		**67**		**33**	
	Prosthetic Side Pre	1.33		1.31		0.67		0.71		0.19		63		37	
		1.39		1.35		0.67		0.72		0.17		62		38	
		1.33		1.30		0.64		0.70		0.15		62		38	
		1.35		1.33		0.65		0.72		0.17		62		38	
		1.26		1.22		0.64		0.68		0.20		62		38	
		1.40		1.28		0.68		0.70		0.21		61		39	
		1.26		1.31		0.63		0.73		0.19		63		37	
		1.29		1.38		0.62		0.74		0.18		62		38	
		1.28		1.38		0.67		0.77		0.19		65		35	
		1.31		1.39		0.65		0.74		0.20		65		35	
	Average	**1.32**		**1.32**		**0.65**		**0.72**		**0.19**		**62**		**38**	
	Prosthetic Side Post	1.30		1.34		0.66		0.72		0.14		63		37	
		1.38		1.32		0.68		0.71		0.15		61		39	
		1.35		1.39		0.64		0.73		0.13		62		38	
		1.37		1.35		0.64		0.66		0.16		62		38	
		1.31	**0.06**	1.38	**0.02**	0.63	**0.11**	0.72	**0.88**	0.13	**0.00**	63	**0.44**	37	**0.44**
		1.37		1.32		0.73		0.70		0.16		62		38	
		1.37		1.32		0.73		0.70		0.16		62		38	
		1.35		1.42		0.69		0.74		0.15		65		35	
		1.37		1.43		0.68		0.77		0.16		63		37	
		1.34		1.45		0.63		0.77		0.12		65		35	
	Average	**1.35**		**1.37**		**0.67**		**0.72**		**0.15**		**63**		**37**	

Table C.1c: *Individual spatiotemporal characteristics of Subject 3*

		Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)	TTEST
		1.22		1.13		0.56		0.65		0.04		66		34	
		1.14		1.12		0.51		0.59		0.14		66		34	
		1.03		1.13		0.41		0.52		0.12		71		29	
		1.37		1.12		0.66		0.59		0.07		62		38	
	Intact Side Pre	1.28		1.13		0.60		0.60		0.12		63		37	
		1.36		1.17		0.66		0.60		0.10		64		36	
		1.30		1.20		0.63		0.60		0.07		65		35	
		1.33		1.18		0.76		0.64		0.10		64		36	
		1.26		1.23		0.60		0.65		0.15		64		36	
		1.14		1.20		0.50		0.60		0.10		65		35	
	Average	**1.24**		**1.16**		**0.59**		**0.61**		**0.10**		**65**		**35**	
		1.41		1.23		0.67		0.62		0.04		64		36	
		1.28		1.26		0.58		0.63		0.10		66		34	
		1.26		1.30		0.58		0.67		0.03		64		36	
		1.15		1.35		0.59		0.70		0.06		67		33	
	Intact Side Post	1.17	**0.84**	1.29	**0.01**	0.57	**0.91**	0.65	**0.17**	0.13	**0.04**	68	**0.46**	32	**0.46**
		1.21		1.26		0.54		0.61		0.11		65		35	
		1.23		1.24		0.60		0.63		0.06		66		34	
		1.23		1.17		0.62		0.60		0.03		66		34	
		1.17		1.25		0.57		0.63		0.04		67		33	
		1.21		1.18		0.58		0.61		0.09		67		33	
SUBJECT 3 (TTC)	**Average**	**1.23**		**1.25**		**0.59**		**0.63**		**0.07**		**66**		**34**	
		1.17		1.18		0.61		0.54		0.10		67		33	
		1.25		1.17		0.64		0.57		0.03		63		37	
		1.14		1.20		0.63		0.53		0.08		66		34	
		1.35		1.12		0.71		0.53		0.07		64		36	
	Prosthetic Side Pre	1.33		1.20		0.70		0.56		0.12		63		37	
		1.49		1.25		0.73		0.60		0.09		62		38	
		1.25		1.15		0.65		0.57		0.07		65		35	
		1.22		1.23		0.66		0.58		0.11		65		35	
		1.05		1.15		0.55		0.55		0.07		67		33	
		1.21		1.23		0.62		0.58		0.11		66		34	
	Average	**1.25**		**1.19**		**0.65**		**0.56**		**0.09**		**65**		**35**	
		1.38		1.20		0.74		0.62		0.08		63		38	
		1.25		1.25		0.70		0.63		0.08		64		36	
		1.21		1.31		0.68		0.63		0.07		65		35	
		1.18		1.35		0.59		0.65		0.07		65		35	
	Prosthetic Side Post	1.16	**0.62**	1.28	**0.05**	0.61	**0.76**	0.64	**0.00**	0.07	**0.24**	67	**0.47**	33	**0.47**
		1.17		1.20		0.63		0.60		0.07		66		34	
		1.24		1.25		0.62		0.62		0.07		64		36	
		1.24		1.18		0.62		0.62		0.57		66		34	
		1.17		1.25		0.60		0.60		0.63		66		34	
		1.21		1.21		0.62		0.57		0.06		67		33	
	Average	**1.22**		**1.25**		**0.64**		**0.62**		**0.17**		**65**		**35**	

Table C.1d *Individual spatiotemporal characteristics of Subject 4*

		Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)	TTEST
SUBJECT 4 (TFC)	Intact Side Pre	1.29		1.40		0.60		0.65		0.17		70		30	
		1.24		1.50		0.61		0.68		0.18		70		30	
		1.19		1.41		0.57		0.64		0.20		71		29	
		1.30		1.40		0.63		0.65		0.21		70		30	
		1.28		1.32		0.60		0.67		0.18		72		28	
		1.27		1.40		0.63		0.65		0.22		70		30	
		1.29		1.46		0.57		0.67		0.15		69		31	
		1.22		1.43		0.55		0.63		0.19		72		28	
		1.32		1.38		0.61		0.60		0.21		70		30	
		1.30		1.41		0.67		0.64		0.15		70		30	
	Average	**1.27**		**1.41**		**0.60**		**0.65**		**0.19**		**70**		**30**	
	Intact Side Post	1.26		1.25		0.67		0.55		0.14		71		29	
		1.34		1.25		0.68		0.55		0.18		69		31	
		1.38		1.29		0.68		0.54		0.24		70		30	
		1.29		1.34		0.70		0.57		0.19		70		30	
		1.39	**0.02**	1.29	**0.00**	0.71	**0.00**	0.57	**0.00**	0.20	**0.23**	68	**0.02**	32	**0.02**
		1.45		1.38		0.75		0.62		0.17		68		32	
		1.35		1.34		0.63		0.57		0.16		70		30	
		1.32		1.31		0.73		0.60		0.15		71		29	
		1.41		1.28		0.77		0.58		0.06		68		32	
		1.27		1.32		0.67		0.60		0.16		68		32	
	Average	**1.35**		**1.30**		**0.70**		**0.57**		**0.17**		**69**		**31**	
	Prosthetic Side Pre	1.29		1.44		0.69		0.79		0.16		61		39	
		1.26		1.48		0.65		0.80		0.22		61		39	
		1.15		1.38		0.59		0.75		0.21		62		38	
		1.28		1.41		0.68		0.75		0.11		61		39	
		1.25		1.41		0.65		0.74		0.19		63		37	
		1.34		1.34		0.71		0.77		0.17		60		40	
		1.27		1.38		0.63		0.75		0.16		62		38	
		1.24		1.48		0.71		0.79		0.19		62		38	
		1.26		1.35		0.65		0.75		0.21		59		41	
		1.36		1.42		0.69		0.78		0.15		60		40	
	Average	**1.27**		**1.41**		**0.67**		**0.77**		**0.18**		**61**		**39**	
	Prosthetic Side Post	1.24		1.25		0.57		0.70		0.18		58		42	
		1.21		1.24		0.53		0.70		0.17		58		42	
		1.38		1.30		0.66		0.70		0.12		57		43	
		1.34		1.33		0.64		0.76		0.20		57		43	
		1.38	**0.10**	1.29	**0.00**	0.67	**0.31**	0.72	**0.02**	0.17	**0.98**	58	**0.00**	42	**0.00**
		1.39		1.34		0.70		0.76		0.24		59		41	
		1.25		1.34		0.72		0.77		0.16		59		41	
		1.41		1.35		0.68		0.75		0.15		57		43	
		1.42		1.31		0.64		0.70		0.23		57		43	
		1.29		1.34		0.60		0.73		0.16		60		40	
	Average	**1.33**		**1.31**		**0.64**		**0.73**		**0.18**		**58**		**42**	

Table C.1e: *Individual spatiotemporal characteristics of Subject 5*

		Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)	TTEST
SUBJECT 5 (TTT-NR)	Intact Side Pre	1.04		1.07		0.64		0.48		0.07		74		26	
		1.21		1.17		0.61		0.49		0.10		72		28	
		1.06		1.14		0.56		0.48		0.08		74		26	
		1.15		1.21		0.61		0.53		0.04		69		31	
		1.02		1.17		0.58		0.53		0.08		75		25	
		1.05		1.05		0.60		0.49		0.04		69		31	
		1.00		1.10		0.52		0.47		0.05		73		27	
		1.13		1.14		0.56		0.45		0.12		73		27	
		1.02		1.08		0.54		0.46		0.08		74		26	
		1.08		1.17		0.62		0.50		0.04		74		26	
	Average	**1.08**		**1.13**		**0.58**		**0.49**		**0.07**		**73**		**27**	
	Intact Side Post	1.03		1.18		0.56		0.49		0.10		70		30	
		1.07		1.33		0.56		0.54		0.03		75		25	
		1.03		1.11		0.58		0.51		0.06		71		29	
		1.06		1.12		0.57		0.52		0.19		69		31	
		1.07	**0.52**	1.14	**0.21**	0.58	**0.36**	0.53	**0.03**	0.06	**0.37**	68	**0.06**	32	**0.06**
		1.15		1.14		0.62		0.50		0.13		69		31	
		1.16		1.10		0.64		0.49		0.10		70		30	
		1.17		1.13		0.64		0.50		0.11		69		31	
		1.09		1.22		0.64		0.54		0.04		74		26	
		1.11		1.18		0.64		0.50		0.10		72		28	
	Average	**1.09**		**1.17**		**0.60**		**0.51**		**0.09**		**71**		**29**	
	Prosthetic Side Pre	1.14		1.11		0.50		0.64		0.09		58		42	
		1.09		1.03		0.55		0.59		0.20		62		38	
		1.11		1.15		0.60		0.68		0.10		58		42	
		1.04		1.15		0.54		0.68		0.08		62		38	
		1.07		1.19		0.48		0.66		0.04		60		40	
		1.00		1.16		0.46		0.65		0.15		60		40	
		1.08		1.12		0.45		0.56		0.13		60		40	
		1.04		1.08		0.57		0.68		0.10		62		38	
		1.15		1.18		0.53		0.68		0.17		59		41	
		1.04		1.06		0.49		0.58		0.17		65		35	
	Average	**1.08**		**1.12**		**0.52**		**0.64**		**0.12**		**61**		**39**	
	Prosthetic Side Post	1.01		1.15		0.45		0.66		0.04		59		41	
		1.06		1.35		0.50		0.80		0.04		56		44	
		1.04		1.12		0.45		0.61		0.10		61		39	
		0.98		1.16		0.49		0.60		0.04		61		39	
		1.03	**0.56**	1.07	**0.23**	0.49	**0.76**	0.62	**0.56**	0.07	**0.01**	63	**0.25**	37	**0.25**
		1.14		1.13		0.52		0.63		0.04		59		41	
		1.12		1.14		0.52		0.61		0.04		58		42	
		1.22		1.13		0.58		0.63		0.04		59		41	
		1.19		1.27		0.56		0.73		0.06		57		43	
		1.19		1.19		0.55		0.69		0.09		57		43	
	Average	**1.10**		**1.17**		**0.51**		**0.66**		**0.06**		**59**		**41**	

Table C.1f: *Individual spatiotemporal characteristics of Subject 6*

		Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)	TTEST
SUBJECT 6(TTT)		1.06		1.30		0.51		0.62		0.13		73		27	
		1.18		1.11		0.60		0.55		0.16		71		29	
		1.14		1.21		0.54		0.59		0.13		69		31	
		1.14		1.20		0.55		0.58		0.13		71		29	
	Intact Side Pre	1.13		1.16		0.57		0.55		0.12		72		28	
		1.17		1.16		0.57		0.55		0.17		70		30	
		1.17		1.12		0.57		0.55		0.18		70		30	
		1.17		1.11		0.56		0.51		0.12		72		28	
		1.12		1.16		0.57		0.55		0.18		72		28	
		1.13		1.16		0.56		0.55		0.14		71		29	
	Average	**1.14**		**1.17**		**0.56**		**0.56**		**0.15**		**71**		**29**	
		1.13		1.23		0.56		0.56		0.16		72		28	
		1.16		1.26		0.56		0.60		0.18		69		31	
		1.17		1.21		0.59		0.58		0.14		70		30	
		1.14		1.24		0.57		0.55		0.19		70		30	
	Intact Side Post	1.19	**0.05**	1.26	**0.06**	0.58	**0.10**	0.58	**0.35**	0.16	**0.01**	68	**0.04**	32	**0.04**
		1.19		1.21		0.58		0.56		0.20		71		29	
		1.12		1.24		0.54		0.55		0.20		72		28	
		1.32		1.13		0.61		0.53		0.18		68		32	
		1.28		1.13		0.61		0.56		0.16		67		33	
		1.18		1.33		0.59		0.64		0.16		69		31	
	Average	**1.19**		**1.22**		**0.58**		**0.57**		**0.17**		**70**		**30**	
		1.05		1.33		0.54		0.70		0.12		68		32	
		1.19		1.14		0.59		0.59		0.09		65		35	
		1.21		1.12		0.62		0.60		0.15		65		35	
		1.14		1.21		0.59		0.63		0.12		66		34	
	Prosthetic Side Pre	1.12		1.21		0.58		0.63		0.14		68		32	
		1.11		1.18		0.59		0.63		0.14		67		33	
		1.17		1.13		0.60		0.61		0.10		66		34	
		1.12		1.11		0.61		0.60		0.20		66		34	
		1.11		1.14		0.55		0.59		0.16		68		32	
		1.15		1.18		0.56		0.60		0.17		67		33	
	Average	**1.14**		**1.17**		**0.58**		**0.62**		**0.14**		**67**		**33**	
		1.16		1.25		0.57		0.67		0.18		68		32	
		1.15		1.25		0.59		0.66		0.17		68		32	
		1.18		1.23		0.59		0.65		0.14		66		34	
		1.15		1.22		0.58		0.66		0.16		66		34	
	Prosthetic Side Post	1.18	**0.11**	1.24	**0.06**	0.59	**0.19**	0.66	**0.02**	0.17	**0.08**	66	**0.93**	34	**0.93**
		1.19		1.19		0.62		0.65		0.17		66		34	
		1.11		1.23		0.57		0.68		0.19		68		32	
		1.27		1.14		0.66		0.60		0.17		64		36	
		1.28		1.15		0.66		0.60		0.14		65		35	
		1.15		1.30		0.59		0.68		0.16		68		32	
	Average	**1.18**		**1.22**		**0.60**		**0.65**		**0.16**		**67**		**33**	

Table C.1g: *Individual spatiotemporal characteristics of Subject 7*

		Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)	TTEST
SUBJECT 7(TFT)	Intact Side Pre	1.44		1.23		0.64		0.57		0.11		65		35	
		1.32		1.18		0.70		0.63		0.06		65		35	
		1.23		1.24		0.62		0.67		0.03		68		32	
		1.26		1.21		0.60		0.64		0.01		67		33	
		1.24		1.24		0.63		0.63		0.08		65		35	
		1.42		1.33		0.67		0.64		0.03		65		35	
		1.41		1.38		0.63		0.68		0.05		62		38	
		1.24		1.20		0.60		0.60		0.10		67		33	
		1.31		1.37		0.63		0.68		0.05		66		34	
		1.30		1.32		0.64		0.65		0.09		66		34	
	Average	**1.32**		**1.27**		**0.64**		**0.64**		**0.06**		**66**		**34**	
	Intact Side Post	1.30		1.23		0.63		0.58		0.11		67		33	
		1.39		1.21		0.66		0.59		0.03		66		34	
		1.30		1.30		0.62		0.60		0.06		67		33	
		1.28		1.35		0.61		0.62		0.06		68		32	
		1.29	**0.22**	1.30	**0.40**	0.64	**0.67**	0.62	**0.03**	0.04	**0.93**	66	**0.01**	34	**0.01**
		1.19		1.31		0.56		0.61		0.09		68		32	
		1.24		1.35		0.68		0.68		0.06		69		31	
		1.23		1.30		0.65		0.62		0.05		69		31	
		1.26		1.25		0.60		0.58		0.07		69		31	
		1.23		1.30		0.64		0.59		0.06		68		32	
	Average	**1.27**		**1.29**		**0.63**		**0.61**		**0.06**		**68**		**32**	
	Prosthetic Side Pre	1.25		1.11		0.80		0.67		0.10		64		36	
		1.23		1.29		0.61		0.62		0.10		66		34	
		1.24		1.27		0.64		0.63		0.12		65		35	
		1.24		1.22		0.61		0.59		0.06		65		35	
		1.32		1.26		0.74		0.69		0.09		62		38	
		1.24		1.27		0.79		0.70		0.12		64		36	
		1.18		1.19		0.59		0.59		0.10		64		36	
		1.32		1.24		0.67		0.63		0.06		62		38	
		1.26		1.31		0.68		0.70		0.09		64		36	
		1.28		1.28		0.66		0.67		0.07		64		36	
	Average	**1.26**		**1.24**		**0.68**		**0.65**		**0.09**		**64**		**36**	
	Prosthetic Side Post	1.32		1.22		0.69		0.64		0.14		61		39	
		1.39		1.22		0.72		0.62		0.16		61		39	
		1.32		1.25		0.67		0.70		0.05		61		39	
		1.26		1.28		0.67		0.74		0.11		62		38	
		1.30	**0.19**	1.26	**0.21**	0.65	**0.54**	0.68	**0.10**	0.07	**0.95**	62	**0.00**	38	**0.00**
		1.16		1.29		0.60		0.68		0.13		64		36	
		1.33		1.41		0.65		0.73		0.08		61		39	
		1.29		1.32		0.63		0.70		0.10		60		40	
		1.25		1.26		0.66		0.68		0.03		60		40	
		1.29		1.28		0.65		0.70		0.03		59		41	
	Average	**1.29**		**1.28**		**0.66**		**0.69**		**0.09**		**61**		**39**	

Table C.1h: *Individual spatiotemporal characteristics of Subject 8*

		Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)
SUBJECT 8 (TFT)		1.19		1.15		0.54		0.53		0.21		68		32
		1.23		1.15		0.54		0.54		0.14		68		32
		1.24		1.23		0.55		0.57		0.20		68		32
		1.25		1.20		0.52		0.56		0.18		68		32
	Intact Side Pre	1.24		1.19		0.54		0.54		0.17		69		31
		1.20		1.27		0.52		0.59		0.21		70		30
		1.21		1.09		0.51		0.50		0.23		67		33
		1.20		1.27		0.59		0.60		0.18		69		31
		1.27		1.20		0.51		0.52		0.15		68		32
		1.21		1.22		0.55		0.56		0.18		69		31
	Average	**1.22**		**1.20**		**0.54**		**0.55**		**0.19**		**68**		**32**
		1.34		1.13		0.56		0.54		0.19		65		35
		1.40		1.32		0.59		0.61		0.18		67		33
		1.35		1.35		0.53		0.63		0.18		67		33
		1.32		1.35		0.48		0.58		0.24		69		31
	Intact Side Post	1.26	**0.48**	1.38	**0.01**	0.53	**0.27**	0.64	**0.01**	0.20	**0.45**	69	**0.27**	31
		1.15		1.23		0.51		0.59		0.20		69		31
		1.22		1.27		0.52		0.61		0.20		68		32
		1.17		1.25		0.47		0.60		0.19		68		32
		1.16		1.25		0.51		0.60		0.15		68		32
		1.10		1.29		0.50		0.56		0.20		69		31
	Average	**1.25**		**1.28**		**0.52**		**0.60**		**0.19**		**68**		**32**
		1.23		1.15		0.65		0.61		0.22		64		36
		1.28		1.21		0.69		0.67		0.21		64		36
		1.23		1.15		0.70		0.65		0.21		65		35
		1.19		1.25		0.68		0.68		0.16		67		33
	Prosthetic Side Pre	1.22		1.13		0.70		0.60		0.25		63		37
		1.25		1.28		0.66		0.69		0.16		65		35
		1.27		1.17		0.76		0.65		0.16		63		37
		1.18		1.18		0.66		0.63		0.19		66		34
		1.24		1.22		0.69		0.66		0.16		65		35
		1.19		1.19		0.66		0.63		0.19		66		34
	Average	**1.23**		**1.19**		**0.68**		**0.65**		**0.19**		**65**		**35**
		1.29		1.16		0.78		0.59		0.18		62		38
		1.36		1.27		0.81		0.71		0.20		63		38
		1.28		1.29		0.82		0.73		0.20		65		35
		1.15		1.21		0.84		0.76		0.16		66		34
	Prosthetic Side Post	1.25	**0.90**	1.32	**0.05**	0.74	**0.06**	0.74	**0.06**	0.13	**0.61**	65	**0.87**	35
		1.20		1.21		0.64		0.65		0.20		67		33
		1.24		1.30		0.70		0.66		0.18		64		36
		1.17		1.25		0.70		0.65		0.18		66		34
		1.19		1.26		0.68		0.66		0.24		65		35
		1.16		1.24		0.67		0.68		0.17		64		36
	Average	**1.23**		**1.25**		**0.74**		**0.68**		**0.18**		**65**		**35**

Table C.1i: *Individual spatiotemporal characteristics of Subject 9*

		Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)	TTEST
SUBJECT 9 (TFC)	Intact Side Pre	1.13		1.24		0.55		0.52		0.17		70		30	
		1.09		1.24		0.45		0.51		0.14		69		31	
		1.02		1.25		0.44		0.52		0.16		71		29	
		1.04		1.16		0.49		0.50		0.22		67		33	
		1.04		1.14		0.48		0.45		0.11		72		28	
		1.12		1.19		0.50		0.45		0.14		70		30	
		1.15		1.24		0.52		0.46		0.15		70		30	
		1.22		1.19		0.50		0.46		0.14		71		29	
		1.14		1.18		0.54		0.47		0.20		70		30	
		1.16		1.17		0.53		0.46		0.14		69		31	
	Average	**1.11**		**1.20**		**0.50**		**0.48**		**0.15**		**70**		**30**	
	Intact Side Post	1.15		1.23		0.50		0.48		0.15		71		29	
		1.16		1.20		0.50		0.47		0.15		70		30	
		1.10		1.16		0.55		0.50		0.12		70		30	
		1.17		1.16		0.56		0.44		0.26		72		28	
		1.20	**0.02**	1.25	**0.80**	0.50	**0.02**	0.49	**0.70**	0.16	**0.91**	70	**0.68**	30	**0.68**
		1.23		1.22		0.57		0.50		0.14		71		29	
		1.22		1.21		0.58		0.50		0.14		70		30	
		1.15		1.20		0.59		0.51		0.12		69		31	
		1.18		1.25		0.58		0.49		0.19		70		30	
		1.15		1.16		0.52		0.49		0.11		71		29	
	Average	**1.17**		**1.20**		**0.54**		**0.49**		**0.15**		**70**		**30**	
	Prosthetic Side Pre	1.18		1.25		0.63		0.73		0.16		63		37	
		1.10		1.25		0.60		0.74		0.20		63		37	
		1.03		1.24		0.64		0.73		0.15		66		34	
		1.05		1.19		0.55		0.66		0.02		65		35	
		1.16		1.15		0.65		0.70		0.11		62		38	
		1.09		1.19		0.63		0.70		0.11		63		37	
		1.18		1.20		0.66		0.74		0.08		60		40	
		1.18		1.18		0.68		0.72		0.10		61		39	
		1.18		1.16		0.60		0.71		0.19		59		41	
		1.16		1.18		0.63		0.70		0.17		61		39	
	Average	**1.13**		**1.20**		**0.63**		**0.71**		**0.13**		**62**		**38**	
	Prosthetic Side Post	1.12		1.20		0.65		0.76		0.18		62		38	
		1.13		1.17		0.64		0.70		0.14		61		39	
		1.15		1.20		0.60		0.70		0.18		63		37	
		1.15		1.15		0.61		0.72		0.16		61		39	
		1.15	**0.03**	1.23	**0.73**	0.65	**0.23**	0.75	**0.45**	0.20	**0.06**	61	**0.26**	39	**0.26**
		1.26		1.23		0.68		0.73		0.12		61		39	
		1.25		1.22		0.67		0.71		0.23		62		38	
		1.23		1.22		0.64		0.70		0.23		62		38	
		1.28		1.25		0.71		0.76		0.13		59		41	
		1.14		1.18		0.62		0.69		0.22		63		37	
	Average	**1.19**		**1.20**		**0.65**		**0.72**		**0.18**		**62**		**38**	

Table C.1j: *Individual spatiotemporal characteristics of Subject 10*

Subject	Condition	Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)	TTEST
SUBJECT 10 (TFC)	Intact Side Pre	1.45		1.25		0.76		0.60		0.20		67		33	
		1.42		1.33		0.74		0.66		0.14		68		32	
		1.40		1.32		0.64		0.58		0.16		68		32	
		1.42		1.31		0.72		0.63		0.18		66		34	
		1.34		1.42		0.71		0.70		0.12		71		29	
		1.41		1.33		0.69		0.64		0.18		68		32	
		1.25		1.38		0.67		0.70		0.11		71		29	
		1.26		1.40		0.64		0.70		0.16		69		31	
		1.25		1.41		0.64		0.69		0.16		69		31	
		1.29		1.38		0.68		0.64		0.22		68		32	
	Average	**1.35**		**1.35**		**0.69**		**0.65**		**0.16**		**68**		**32**	
	Intact Side Post	1.28		1.35		0.67		0.63		0.19		69		31	
		1.40		1.43		0.70		0.67		0.17		70		30	
		1.32		1.36		0.69		0.66		0.17		69		31	
		1.30		1.36		0.67		0.63		0.18		70		30	
		1.28	**0.09**	1.40	**0.09**	0.65	**0.40**	0.66	**0.53**	0.18	**0.67**	70	**0.08**	30	**0.08**
		1.29		1.40		0.66		0.67		0.24		70		30	
		1.26		1.36		0.66		0.69		0.14		69		31	
		1.32		1.41		0.68		0.66		0.14		70		30	
		1.30		1.36		0.70		0.68		0.10		69		31	
		1.28		1.40		0.67		0.66		0.16		70		30	
	Average	**1.30**		**1.38**		**0.68**		**0.66**		**0.17**		**70**		**30**	
	Prosthetic Side Pre	1.45		1.23		0.69		0.64		0.18		63		38	
		1.43		1.37		0.70		0.70		0.13		64		36	
		1.34		1.27		0.70		0.69		0.16		64		36	
		1.39		1.30		0.70		0.68		0.14		64		36	
		1.37		1.45		0.66		0.75		0.14		64		36	
		1.36		1.29		0.72		0.70		0.14		66		34	
		1.26		1.40		0.58		0.70		0.17		67		33	
		1.21		1.36		0.62		0.70		0.14		70		30	
		1.26		1.38		0.61		0.72		0.20		68		32	
		1.31		1.31		0.63		0.68		0.17		65		35	
	Average	**1.34**		**1.34**		**0.66**		**0.70**		**0.16**		**65**		**35**	
	Prosthetic Side Post	1.32		1.36		0.61		0.72		0.17		63		37	
		1.35		1.35		0.70		0.76		0.15		66		34	
		1.34		1.38		0.63		0.70		0.21		64		36	
		1.29		1.35		0.62		0.72		0.14		63		37	
		1.29	**0.08**	1.39	**0.10**	0.61	**0.07**	0.75	**0.00**	0.20	**0.23**	62	**0.08**	38	**0.08**
		1.28		1.41		0.63		0.74		0.18		63		37	
		1.27		1.39		0.63		0.73		0.16		64		36	
		1.27		1.40		0.61		0.71		0.20		65		35	
		1.27		1.34		0.64		0.75		0.14		66		34	
		1.30		1.41		0.60		0.68		0.17		64		36	
	Average	**1.30**		**1.38**		**0.63**		**0.73**		**0.17**		**64**		**36**	

Table C.1k: *Individual spatiotemporal characteristics of Subject 11*

		Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)	TTEST
		1.24		1.24		0.61		0.55		0.08		59		41	
		1.25		1.28		0.61		0.58		0.11		67		33	
		1.18		1.25		0.61		0.60		0.09		67		33	
		1.22		1.29		0.63		0.60		0.08		69		31	
	Intact Side Pre	1.13		1.39		0.60		0.61		0.08		71		29	
		1.14		1.41		0.57		0.64		0.05		71		29	
		1.18		1.25		0.60		0.58		0.09		67		33	
		1.20		1.29		0.62		0.58		0.15		70		30	
		1.19		1.28		0.57		0.56		0.05		60		40	
		1.23		1.31		0.60		0.60		0.09		59		41	
	Average	**1.20**		**1.30**		**0.60**		**0.59**		**0.09**		**66**		**34**	
		1.12		1.39		0.57		0.63		0.10		70		30	
		1.21		1.35		0.62		0.64		0.02		67		33	
		1.17		1.21		0.59		0.57		0.12		68		32	
		1.18		1.23		0.60		0.60		0.11		67		33	
	Intact Side Post	1.22	**0.92**	1.27	**0.20**	0.62	**0.88**	0.59	**0.92**	0.05	**0.82**	66	**0.36**	34	**0.36**
		1.30		1.18		0.66		0.55		0.06		66		34	
		1.22		1.14		0.59		0.53		0.12		68		32	
		1.14		1.27		0.56		0.60		0.08		69		31	
		1.20		1.25		0.60		0.59		0.12		69		31	
		1.22		1.23		0.61		0.60		0.12		68		32	
SUBJECT 11 (TTT)	**Average**	**1.20**		**1.25**		**0.60**		**0.59**		**0.09**		**68**		**32**	
		1.19		1.18		0.63		0.68		0.13		51		49	
		1.25		1.27		0.64		0.68		0.06		62		38	
		1.22		1.26		0.61		0.66		0.07		64		36	
		1.20		1.30		0.57		0.65		0.07		62		38	
	Prosthetic Side Pre	1.15		1.36		0.54		0.75		0.13		62		38	
		1.14		1.39		0.56		0.77		0.10		65		35	
		1.18		1.23		0.58		0.65		0.07		63		37	
		1.19		1.26		0.59		0.65		0.12		65		35	
		1.23		1.26		0.58		0.70		0.06		62		38	
		1.22		1.27		0.60		0.72		0.03		54		46	
	Average	**1.20**		**1.28**		**0.59**		**0.69**		**0.08**		**61**		**39**	
		1.12		1.36		0.55		0.77		0.04		63		37	
		1.18		1.34		0.59		0.71		0.07		64		36	
		1.17		1.20		0.58		0.65		0.09		64		36	
		1.23		1.25		0.60		0.66		0.10		62		38	
	Prosthetic Side Post	1.23	**0.74**	1.28	**0.71**	0.61	**0.97**	0.68	**0.45**	0.06	**0.36**	61	**0.36**	39	**0.36**
		1.29		1.16		0.65		0.63		0.07		61		39	
		1.13		1.28		0.57		0.68		0.08		62		38	
		1.14		1.25		0.57		0.66		0.06		64		36	
		1.20		1.26		0.60		0.68		0.06		62		38	
		1.21		1.25		0.59		0.65		0.07		62		38	
	Average	**1.19**		**1.26**		**0.59**		**0.67**		**0.07**		**62**		**38**	

Table C.1l: *Individual spatiotemporal characteristics of Subject 12*

		Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)
SUBJECT 12 (TTT)	Intact Side Pre	1.43		1.31		0.74		0.63		0.09		64		36
		1.41		1.47		0.80		0.85		0.01		65		35
		1.39		1.41		0.71		0.75		0.07		65		35
		1.44		1.39		0.69		0.76		0.01		65		35
		1.20		1.25		0.74		0.63		0.04		64		36
		1.60		1.53		0.75		0.74		0.13		63		37
		1.43		1.46		0.76		0.76		0.12		60		40
		1.40		1.46		0.70		0.76		0.15		64		36
		1.36		1.44		0.72		0.74		0.07		63		37
		1.46		1.49		0.70		0.73		0.08		63		37
	Average	**1.41**		**1.42**		**0.73**		**0.73**		**0.08**		**64**		**36**
	Intact Side Post	1.50		1.18		0.78		0.65		0.07		62		38
		1.35		1.46		0.71		0.76		0.11		64		36
		1.44		1.53		0.68		0.79		0.12		65		35
		1.45		1.45		0.77		0.83		0.07		65		35
		1.48	**0.35**	1.49	**0.58**	0.68	**0.53**	0.76	**0.76**	0.14	**0.02**	62	**0.19**	38
		1.56		1.38		0.71		0.70		0.10		61		39
		1.47		1.33		0.72		0.72		0.14		63		37
		1.44		1.30		0.70		0.68		0.16		63		38
		1.39		1.42		0.74		0.75		0.11		64		36
		1.36		1.44		0.69		0.79		0.11		63		37
	Average	**1.44**		**1.40**		**0.72**		**0.74**		**0.11**		**63**		**37**
	Prosthetic Side Pre	1.47		1.27		0.69		0.68		0.10		61		39
		1.50		1.57		0.70		0.72		0.11		63		37
		1.40		1.45		0.69		0.69		0.16		64		36
		1.41		1.44		0.72		0.68		0.15		64		36
		1.45		1.25		0.46		0.63		0.29		60		40
		1.51		1.55		0.86		0.80		0.16		56		44
		1.49		1.44		0.73		0.68		0.19		63		37
		1.41		1.48		0.71		0.72		0.15		62		38
		1.43		1.43		0.64		0.70		0.19		63		37
		1.43		1.48		0.76		0.76		0.14		60		40
	Average	**1.45**		**1.43**		**0.70**		**0.70**		**0.16**		**62**		**38**
	Prosthetic Side Post	1.55		1.20		0.77		0.55		0.14		64		36
		1.50		1.15		0.77		0.53		0.14		65		35
		1.39		1.48		0.69		0.72		0.10		62		38
		1.41		1.46		0.76		0.75		0.09		66		34
		1.53	**0.54**	1.55	**0.37**	0.76	**0.10**	0.73	**0.21**	0.12	**0.05**	64	**0.02**	36
		1.45		1.43		0.80		0.73		0.13		64		36
		1.46		1.32		0.85		0.68		0.18		64		36
		1.43		1.30		0.73		0.62		0.11		63		37
		1.46		1.42		0.72		0.68		0.12		63		37
		1.41		1.48		0.72		0.70		0.11		65		35
	Average	**1.46**		**1.38**		**0.76**		**0.67**		**0.12**		**64**		**36**

Table C.1m: *Individual spatiotemporal characteristics of Subject 14*

		Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)	TTEST
SUBJECT 14 (TTC)	Intact Side Pre	0.95		1.10		0.52		0.60		0.08		70		30	
		1.07		1.12		0.45		0.52		0.14		68		32	
		1.19		1.17		0.50		0.57		0.16		65		35	
		1.18		1.18		0.55		0.56		0.14		65		35	
		1.10		1.09		0.56		0.56		0.07		64		36	
		1.13		1.13		0.49		0.53		0.11		65		35	
		1.16		1.09		0.52		0.55		0.06		66		34	
		1.18		1.10		0.54		0.52		0.16		65		35	
		1.11		1.22		0.43		0.56		0.17		67		33	
		1.11		1.23		0.45		0.58		0.13		66		34	
	Average	**1.12**		**1.14**		**0.50**		**0.55**		**0.12**		**66**		**34**	
	Intact Side Post	1.06		1.03		0.51		0.48		0.17		68		32	
		1.18		1.09		0.56		0.51		0.10		67		33	
		1.27		1.17		0.56		0.49		0.16		65		35	
		1.15		1.14		0.54		0.54		0.12		69		31	
		1.15	**0.46**	1.14	**0.31**	0.55	**0.01**	0.55	**0.06**	0.11	**0.95**	65	**0.04**	35	**0.04**
		1.15		1.06		0.56		0.50		0.15		68		32	
		1.20		1.13		0.53		0.51		0.12		67		33	
		1.10		1.17		0.59		0.55		0.16		66		34	
		1.03		1.14		0.55		0.57		0.06		71		29	
		1.07		1.17		0.54		0.54		0.07		70		30	
	Average	**1.14**		**1.12**		**0.55**		**0.52**		**0.12**		**68**		**32**	
	Prosthetic Side Pre	1.10		1.20		0.58		0.61		0.11		63		37	
		1.14		1.13		0.62		0.60		0.11		61		39	
		1.09		1.09		0.63		0.61		0.14		63		37	
		1.09		1.11		0.60		0.58		0.15		63		37	
		1.11		1.12		0.58		0.57		0.18		62		38	
		1.14		1.12		0.62		0.58		0.15		62		38	
		1.18		1.07		0.64		0.55		0.15		63		37	
		1.06		1.21		0.63		0.65		0.06		63		37	
		1.10		1.18		0.61		0.61		0.15		64		36	
		1.08		1.21		0.67		0.65		0.14		64		36	
	Average	**1.11**		**1.14**		**0.62**		**0.60**		**0.13**		**63**		**37**	
	Prosthetic Side Post	1.06		1.05		0.55		0.55		0.13		60		40	
		1.11		1.09		0.63		0.58		0.11		61		39	
		1.27		1.11		0.71		0.62		0.18		58		42	
		1.12		1.13		0.61		0.60		0.08		61		39	
		1.14	**0.31**	1.14	**0.14**	0.60	**0.37**	0.59	**0.28**	0.12	**0.87**	62	**0.00**	38	**0.00**
		1.11		1.08		0.59		0.55		0.14		59		41	
		1.13		1.09		0.60		0.58		0.13		61		39	
		1.23		1.15		0.64		0.60		0.12		59		41	
		1.11		1.17		0.56		0.60		0.15		62		38	
		1.09		1.15		0.55		0.60		0.16		62		38	
	Average	**1.14**		**1.12**		**0.60**		**0.59**		**0.13**		**60**		**40**	

Table C.1n: *Individual spatiotemporal characteristics of Subject 15*

		Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)	TTEST
SUBJECT 15 (TFT)	Intact Side Pre	1.39		1.25		0.67		0.61		0.14		66		34	
		1.39		1.25		0.67		0.61		0.14		66		34	
		1.38		1.44		0.63		0.72		0.15		68		32	
		1.32		1.34		0.60		0.66		0.12		68		32	
		1.34		1.36		0.63		0.69		0.09		67		33	
		1.28		1.40		0.57		0.67		0.13		70		30	
		1.34		1.43		0.61		0.70		0.17		69		31	
		1.28		1.42		0.61		0.72		0.06		67		33	
		1.26		1.40		0.58		0.70		0.15		69		31	
		1.29		1.36		0.63		0.68		0.12		70		30	
	Average	**1.33**		**1.37**		**0.62**		**0.68**		**0.13**		**68**		**32**	
	Intact Side Post	1.34		1.40		0.63		0.69		0.16		68		32	
		1.30		1.32		0.61		0.61		0.16		70		30	
		1.24		1.35		0.60		0.58		0.11		70		30	
		1.34	**0.52**	1.39	**0.59**	0.63	**0.29**	0.59	**0.38**	0.17	**0.64**	69	**0.07**	31	**0.07**
		1.29		1.41		0.61		0.70		0.13		69		31	
		1.36		1.33		0.71		0.68		0.11		68		32	
		1.27		1.43		0.70		0.72		0.09		71		29	
		1.34		1.42		0.63		0.68		0.18		70		30	
	Average	**1.31**		**1.38**		**0.64**		**0.66**		**0.14**		**69**		**31**	
	Prosthetic Side Pre	1.39		1.22		0.72		0.64		0.14		64		36	
		1.39		1.22		0.72		0.64		0.14		64		36	
		1.34		1.41		0.75		0.73		0.12		67		33	
		1.31		1.34		0.71		0.68		0.12		66		34	
		1.31		1.36		0.71		0.68		0.14		67		33	
		1.26		1.39		0.69		0.72		0.09		67		33	
		1.29		1.39		0.73		0.73		0.13		68		32	
		1.24		1.40		0.67		0.70		0.16		69		31	
		1.26		1.41		0.69		0.70		0.09		68		32	
		1.31		1.35		0.66		0.69		0.13		67		33	
	Average	**1.31**		**1.35**		**0.70**		**0.69**		**0.12**		**67**		**33**	
	Prosthetic Side Post	1.31		1.37		0.71		0.72		0.15		68		32	
		1.27		1.28		0.66		0.66		0.14		66		34	
		1.36		1.34		0.72		0.69		0.08		66		34	
		1.25		1.27		0.65		0.69		0.10		66		34	
		1.36	**0.66**	1.31	**0.94**	0.73	**0.31**	0.72	**0.49**	0.10	**0.49**	64	**0.50**	36	**0.50**
		1.29		1.35		0.67		0.68		0.04		68		32	
		1.29		1.39		0.69		0.70		0.14		69		31	
		1.42		1.35		0.71		0.68		0.16		66		34	
		1.35		1.45		0.65		0.73		0.15		65		35	
		1.34		1.40		0.71		0.73		0.10		66		34	
	Average	**1.32**		**1.35**		**0.69**		**0.70**		**0.12**		**66**		**34**	

Table C.1o: *Individual spatiotemporal characteristics of Subject 16*

		Stride Length	TTEST	Stride Time	TTEST	Step Length	TTEST	Step Time	TTEST	Step Width	TTEST	Stance Time (%GC)	TTEST	Swing Time (%GC)	TTEST
SUBJECT 16 (TFC)	Intact Side Pre	1.30		1.24		0.65		0.62		0.10		63		37	
		1.35		1.27		0.64		0.63		0.07		63		37	
		1.37		1.32		0.61		0.64		0.10		63		37	
		1.28		1.25		0.62		0.63		0.13		63		37	
		1.27		1.29		0.61		0.63		0.07		65		35	
		1.29		1.26		0.62		0.63		0.06		65		35	
		1.30		1.25		0.63		0.63		0.06		66		34	
		1.33		1.28		0.60		0.61		0.12		65		35	
		1.29		1.24		0.63		0.65		0.15		66		34	
		1.34		1.30		0.66		0.64		0.08		64		36	
	Average	**1.31**		**1.27**		**0.63**		**0.63**		**0.09**		**64**		**36**	
	Intact Side Post	1.34		1.22		0.65		0.59		0.09		64		36	
		1.27		1.23		0.61		0.61		0.08		66		34	
		1.18		1.22		0.63		0.63		0.09		65		35	
		1.24		1.28		0.59		0.63		0.11		65		35	
		1.29	**0.20**	1.25	**0.09**	0.62	**0.22**	0.62	**0.01**	0.09	**0.90**	65	**0.19**	35	**0.19**
		1.29		1.27		0.62		0.63		0.11		64		36	
		1.34		1.24		0.62		0.60		0.12		64		36	
		1.26		1.25		0.59		0.60		0.08		66		34	
		1.28		1.27		0.63		0.63		0.14		65		35	
		1.32		1.23		0.62		0.59		0.03		65		35	
	Average	**1.28**		**1.25**		**0.62**		**0.61**		**0.09**		**65**		**35**	
	Prosthetic Side Pre	1.32		1.24		0.67		0.63		0.14		63		37	
		1.37		1.28		0.73		0.65		0.20		63		37	
		1.31		1.27		0.68		0.65		0.02		63		37	
		1.26		1.27		0.77		0.68		0.12		64		36	
		1.28		1.26		0.65		0.66		0.07		64		36	
		1.31		1.28		0.68		0.65		0.09		63		37	
		1.29		1.28		0.69		0.67		0.13		62		38	
		1.35		1.27		0.71		0.65		0.16		63		37	
		1.29		1.29		0.67		0.64		0.08		65		35	
		1.34		1.27		0.68		0.65		0.07		63		37	
	Average	**1.31**		**1.27**		**0.69**		**0.65**		**0.11**		**63**		**37**	
	Prosthetic Side Post	1.31		1.22		0.69		0.63		0.04		64		36	
		1.26		1.24		0.65		0.63		0.09		64		36	
		1.26		1.25		0.63		0.63		0.10		64		36	
		1.23		1.28		0.65		0.65		0.05		64		36	
		1.29	**0.02**	1.26	**0.00**	0.67	**0.09**	0.63	**0.00**	0.08	**0.12**	63	**0.33**	37	**0.33**
		1.29		1.24		0.67		0.64		0.09		64		36	
		1.30		1.24		0.72		0.64		0.06		64		36	
		1.23		1.23		0.66		0.65		0.05		64		36	
		1.28		1.27		0.65		0.63		0.10		63		37	
		1.29		1.23		0.67		0.63		0.09		64		36	
	Average	**1.27**		**1.24**		**0.67**		**0.64**		**0.07**		**64**		**36**	

Table C.2a: *Control Groups' spatiotemporal results arranged by type, session, and side*

Control Group

Transtibial			Norm. Stride Length (m)	T-Test	Avg Stride Time (s)	T-Test	Norm. Step Length (m)	T-Test	Avg Step Time (s)	T-Test	Avg Step Width (m)	T-Test	Avg Stance Time (%GC)	T-Test	Avg Swing Time (%GC)	T-Test
Pre	I	Subject 3	0.74		1.16		0.35		0.61		0.10		65.1		34.9	
		Subject 14	0.66		1.14		0.29		0.55		0.12		66.2		33.8	
		Subject 16	0.77		1.27		0.37		0.63		0.09		64.4		35.6	
		AVERAGE	**0.72**		**1.19**		**0.34**		**0.60**		**0.11**		**65.2**		**34.8**	
Post	I	Subject 3	0.73		1.25		0.35		0.63		0.07		66.0		34.0	
		Subject 14	0.67		1.12		0.32		0.52		0.12		67.6		32.4	
		Subject 16	0.77		1.27		0.37		0.63		0.09		64.4		35.6	
		AVERAGE	**0.72**	**0.40**	**1.22**	**0.27**	**0.35**	**0.19**	**0.60**	**0.49**	**0.10**	**0.22**	**66.0**	**0.10**	**34.0**	**0.10**
Pre	P	Subject 3	0.74		1.19		0.38		0.56		0.09		64.7		35.3	
		Subject 14	0.65		1.14		0.36		0.60		0.13		62.8		37.2	
		Subject 16	0.77		1.27		0.41		0.65		0.11		63.5		36.5	
		AVERAGE	**0.72**		**1.20**		**0.39**		**0.60**		**0.11**		**63.7**		**36.3**	
Post	P	Subject 3	0.72		1.25		0.38		0.62		0.17		65.2		34.8	
		Subject 14	0.67		1.12		0.35		0.59		0.13		60.3		39.7	
		Subject 16	0.75		1.24		0.39		0.64		0.07		63.8		36.2	
		AVERAGE	**0.71**	**0.31**	**1.20**	**0.47**	**0.38**	**0.05**	**0.61**	**0.37**	**0.13**	**0.34**	**63.1**	**0.32**	**36.9**	**0.32**

Transfemoral			Norm. Avg Stride Length (m)	T-Test	Avg Stride Time (s)	T-Test	Norm. Avg Step Length	T-Test	Avg Step Time (s)	T-Test	Avg Step Width (m)	T-Test	Avg Stance Time (%GC)	T-Test	Avg Swing Time (%GC)	T-Test
Pre	I	Subject 1	0.73		1.20		0.36		0.55		0.15		68.8		31.2	
		Subject 2	0.74		1.36		0.37		0.63		0.20		68.8		31.2	
		Subject 4	0.71		1.41		0.34		0.65		0.19		70.4		29.6	
		Subject 9	0.66		1.20		0.30		0.48		0.15		70.0		30.0	
		Subject 10	0.71		1.35		0.36		0.65		0.16		68.4		31.6	
		AVERAGE	**0.71**		**1.30**		**0.35**		**0.59**		**0.17**		**69.3**		**30.7**	
Post	I	Subject 1	0.74		1.20		0.37		0.55		0.16		68.6		31.4	
		Subject 2	0.76		1.37		0.39		0.65		0.14		67.4		32.6	
		Subject 4	0.75		1.30		0.39		0.57		0.17		69.1		30.9	
		Subject 9	0.70		1.20		0.32		0.49		0.15		70.3		29.7	
		Subject 10	0.69		1.38		0.36		0.66		0.17		69.5		30.5	
		AVERAGE	**0.73**	**0.11**	**1.29**	**0.32**	**0.37**	**0.06**	**0.58**	**0.34**	**0.16**	**0.15**	**69.0**	**0.27**	**31.0**	**0.27**
Pre	P	Subject 1	0.73		1.21		0.37		0.65		0.13		60.4		39.6	
		Subject 2	0.74		1.32		0.37		0.72		0.19		62.5		37.5	
		Subject 4	0.71		1.41		0.37		0.77		0.18		61.2		38.8	
		Subject 9	0.67		1.20		0.37		0.71		0.13		62.4		37.6	
		Subject 10	0.71		1.34		0.35		0.70		0.16		65.3		34.7	
		AVERAGE	**0.71**		**1.30**		**0.37**		**0.71**		**0.16**		**62.4**		**37.6**	
Post	P	Subject 1	0.74		1.20		0.37		0.65		0.15		59.7		40.3	
		Subject 2	0.76		1.37		0.38		0.72		0.15		62.8		37.2	
		Subject 4	0.74		1.31		0.36		0.73		0.18		58.0		42.0	
		Subject 9	0.71		1.20		0.38		0.72		0.18		61.5		38.5	
		Subject 10	0.69		1.38		0.33		0.73		0.17		64.1		35.9	
		AVERAGE	**0.73**	**0.11**	**1.29**	**0.45**	**0.36**	**0.39**	**0.71**	**0.48**	**0.16**	**0.32**	**61.2**	**0.07**	**38.8**	**0.07**

Table C.2b: *Training Groups' spatiotemporal results arranged by type, session, and side*

Training Group

Transtibial			Norm. Avg Stride Length (m)	T-Test	Avg Stride Time (s)	T-Test	Norm. Avg Step Length	T-Test	Avg Step Time (s)	T-Test	Avg Step Width (m)	T-Test	Avg Stance Time (%GC)	T-Test	Avg Swing Time (%GC)	T-Test
Pre	I	Subject 5	0.55		1.13		0.30		0.49		0.07		72.7		27.3	
		Subject 6	0.69		1.17		0.34		0.56		0.15		71.1		28.9	
		Subject 11	0.72		1.30		0.36		0.59		0.09		66.1		33.9	
		Subject 12	0.74		1.42		0.38		0.73		0.08		63.8		36.2	
		AVERAGE	**0.67**		**1.26**		**0.34**		**0.59**		**0.10**		**68.4**		**31.6**	
Post	I	Subject 5	0.56		1.17		0.31		0.51		0.09		70.8		29.2	
		Subject 6	0.72		1.22		0.35		0.57		0.17		69.5		30.5	
		Subject 11	0.72		1.25		0.36		0.59		0.09		67.8		32.2	
		Subject 12	0.76		1.40		0.38		0.74		0.11		63.0		37.0	
		AVERAGE	**0.69**	**0.04**	**1.26**	**0.43**	**0.35**	**0.22**	**0.60**	**0.07**	**0.12**	**0.03**	**67.8**	**0.25**	**32.2**	**0.25**
Pre	P	Subject 5	0.55		1.12		0.26		0.64		0.12		60.6		39.4	
		Subject 6	0.69		1.17		0.35		0.62		0.14		66.6		33.4	
		Subject 11	0.72		1.28		0.35		0.69		0.08		61.0		39.0	
		Subject 12	0.76		1.43		0.36		0.70		0.16		61.6		38.4	
		AVERAGE	**0.68**		**1.25**		**0.33**		**0.66**		**0.13**		**62.4**		**37.6**	
Post	P	Subject 5	0.56		1.17		0.26		0.66		0.06		59.2		40.8	
		Subject 6	0.72		1.22		0.37		0.65		0.16		66.6		33.4	
		Subject 11	0.71		1.26		0.35		0.67		0.07		62.5		37.5	
		Subject 12	0.76		1.38		0.40		0.67		0.12		64.2		35.8	
		AVERAGE	**0.69**	**0.13**	**1.26**	**0.40**	**0.34**	**0.15**	**0.66**	**0.48**	**0.10**	**0.15**	**63.1**	**0.24**	**36.9**	**0.24**

Transfemoral			Norm. Avg Stride Length (m)	T-Test	Avg Stride Time (s)	T-Test	Norm. Avg Step Length	T-Test	Avg Step Time (s)	T-Test	Avg Step Width (m)	T-Test	Avg Stance Time (%GC)	T-Test	Avg Swing Time (%GC)	T-Test
Pre	I	Subject 7	0.73		1.27		0.35		0.64		0.06		65.7		34.3	
		Subject 8	0.63		1.20		0.28		0.55		0.19		68.3		31.7	
		Subject 15	0.74		1.37		0.34		0.68		0.13		68.1		31.9	
		AVERAGE	**0.70**		**1.28**		**0.32**		**0.62**		**0.13**		**67.4**		**32.6**	
Post	I	Subject 7	0.71		1.29		0.35		0.61		0.06		67.7		32.3	
		Subject 8	0.64		1.28		0.27		0.60		0.19		67.8		32.2	
		Subject 15	0.73		1.38		0.36		0.66		0.14		69.3		30.7	
		AVERAGE	**0.69**	**0.29**	**1.32**	**0.11**	**0.32**	**0.47**	**0.62**	**0.48**	**0.13**	**0.07**	**68.3**	**0.18**	**31.7**	**0.18**
Pre	P	Subject 7	0.70		1.24		0.38		0.65		0.09		63.9		36.1	
		Subject 8	0.63		1.19		0.35		0.65		0.19		64.8		35.2	
		Subject 15	0.73		1.35		0.39		0.69		0.12		66.7		33.3	
		AVERAGE	**0.69**		**1.26**		**0.37**		**0.66**		**0.14**		**65.2**		**34.8**	
Post	P	Subject 7	0.72		1.28		0.37		0.69		0.09		61.1		38.9	
		Subject 8	0.63		1.25		0.38		0.68		0.18		64.7		35.3	
		Subject 15	0.74		1.35		0.38		0.70		0.12		66.2		33.8	
		AVERAGE	**0.70**	**0.12**	**1.29**	**0.10**	**0.38**	**0.41**	**0.69**	**0.05**	**0.13**	**0.12**	**64.0**	**0.15**	**36.0**	**0.15**

Table C.3a: *Intact Limb Spatiotemporal Results, Pre- and Post- Testing. T-test between groups*

Group	Test	Limb		Avg Stride Length (m)	T-TEST	Avg Stride Time (s)	T-TEST	Avg Step Length (m)	T-TEST	Avg Step Time (s)	T-TEST	Avg Step Width (m)	T-TEST	Avg StanceTime (%GC)	T-TEST	Avg SwingTime (%GC)
TT Control	Pre	I	Subject 3	1.24		1.16		0.59		0.61		0.10		65.1		34.9
			Subject 14	1.12		1.14		0.50		0.55		0.12		66.2		33.8
			Subject 16	1.31		1.27		0.63		0.63		0.09		64.4		35.6
			AVERAGE	**1.22**		**1.19**		**0.57**		**0.60**		**0.11**		**65.2**		**34.8**
			STDEV	**0.10**		**0.07**		**0.06**		**0.04**		**0.01**		**0.9**		**0.9**
TT Training	Pre	I	Subject 5	1.08		1.13		0.58		0.49		0.07		72.7		27.3
			Subject 6	1.14		1.17		0.56		0.56		0.15		71.1		28.9
			Subject 11	1.20		1.30		0.60		0.59		0.09		66.1		33.9
			Subject 12	1.41		1.42		0.73		0.73		0.08		63.8		36.2
			AVERAGE	**1.21**	**0.86**	**1.26**	**0.48**	**0.62**	**0.42**	**0.59**	**0.96**	**0.10**	**0.64**	**68.4**	**0.26**	**31.6**
			STDEV	**0.15**		**0.13**		**0.08**		**0.10**		**0.03**		**4.2**		**4.2**
TT Control	Post	I	Subject 3	1.23		1.25		0.59		0.63		0.07		66.0		34.0
			Subject 14	1.14		1.12		0.55		0.52		0.12		67.6		32.4
			Subject 16	1.31		1.27		0.63		0.63		0.09		64.4		35.6
			AVERAGE	**1.23**		**1.22**		**0.59**		**0.60**		**0.10**		**66.0**		**34.0**
			STDEV	**0.09**		**0.08**		**0.04**		**0.06**		**0.03**		**1.6**		**1.6**
TT Training	Post	I	Subject 5	1.09		1.17		0.60		0.51		0.09		70.8		29.2
			Subject 6	1.19		1.22		0.58		0.57		0.17		69.5		30.5
			Subject 11	1.20		1.25		0.60		0.59		0.09		67.8		32.2
			Subject 12	1.44		1.40		0.72		0.74		0.11		63.0		37.0
			AVERAGE	**1.23**	**0.97**	**1.26**	**0.56**	**0.63**	**0.42**	**0.60**	**0.91**	**0.12**	**0.45**	**67.8**	**0.45**	**32.2**
			STDEV	**0.15**		**0.10**		**0.06**		**0.10**		**0.04**		**3.4**		**3.4**
TF Control	Pre	I	Subject 1	1.19		1.20		0.59		0.55		0.15		68.8		31.2
			Subject 2	1.32		1.36		0.66		0.63		0.20		68.8		31.2
			Subject 4	1.27		1.41		0.60		0.65		0.19		70.4		29.6
			Subject 9	1.11		1.20		0.50		0.48		0.15		70.0		30.0
			Subject 10	1.35		1.35		0.69		0.65		0.16		68.4		31.6
			AVERAGE	**1.25**		**1.30**		**0.61**		**0.59**		**0.17**		**69.3**		**30.7**
			STDEV	**0.10**		**0.10**		**0.07**		**0.07**		**0.02**		**0.9**		**0.9**
TF Training	Pre	I	Subject 7	1.32		1.27		0.64		0.64		0.06		65.7		34.3
			Subject 8	1.22		1.20		0.54		0.55		0.19		68.3		31.7
			Subject 15	1.33		1.37		0.62		0.68		0.13		68.1		31.9
			AVERAGE	**1.29**	**0.54**	**1.28**	**0.72**	**0.60**	**0.82**	**0.62**	**0.61**	**0.13**	**0.16**	**67.4**	**0.06**	**32.6**
			STDEV	**0.06**		**0.08**		**0.05**		**0.06**		**0.06**		**1.5**		**1.5**
TF Control	Post	I	Subject 1	1.21		1.20		0.61		0.55		0.16		68.6		31.4
			Subject 2	1.36		1.37		0.69		0.65		0.14		67.4		32.6
			Subject 4	1.35		1.30		0.70		0.57		0.17		69.1		30.9
			Subject 9	1.17		1.20		0.54		0.49		0.15		70.3		29.7
			Subject 10	1.30		1.38		0.68		0.66		0.17		69.5		30.5
			AVERAGE	**1.28**		**1.29**		**0.64**		**0.58**		**0.16**		**69.0**		**31.0**
			STDEV	**0.08**		**0.09**		**0.07**		**0.07**		**0.01**		**1.1**		**1.1**
TF Training	Post	I	Subject 7	1.27		1.29		0.63		0.61		0.06		67.7		32.3
			Subject 8	1.25		1.28		0.52		0.60		0.19		67.8		32.2
			Subject 15	1.31		1.38		0.64		0.66		0.14		69.3		30.7
			AVERAGE	**1.28**	**0.99**	**1.32**	**0.66**	**0.60**	**0.36**	**0.62**	**0.47**	**0.13**	**0.41**	**68.3**	**0.37**	**31.7**
			STDEV	**0.03**		**0.05**		**0.07**		**0.03**		**0.06**		**0.9**		**0.9**

Table C.3b: *Prosthetic Limb Spatiotemporal Results, Pre- and Post- Testing. T-test between groups*

TT Control	Pre	P	Subject 3	1.25		1.19		0.65		0.56		0.09		64.7		35.3
			Subject 14	1.11		1.14		0.62		0.60		0.13		62.8		37.2
			Subject 16	1.31		1.27		0.69		0.65		0.11		63.5		36.5
			AVERAGE	**1.22**		**1.20**		**0.65**		**0.60**		**0.11**		**63.7**		**36.3**
			STDEV	**0.10**		**0.06**		**0.04**		**0.05**		**0.02**		**0.9**		**0.9**
TT Training	Pre	P	Subject 5	1.08		1.12		0.52		0.64		0.12		60.6		39.4
			Subject 6	1.14		1.17		0.58		0.62		0.14		66.6		33.4
			Subject 11	1.20		1.28		0.59		0.69		0.08		61.0		39.0
			Subject 12	1.45		1.43		0.70		0.70		0.16		61.6		38.4
			AVERAGE	**1.22**	**0.95**	**1.25**	**0.58**	**0.60**	**0.28**	**0.66**	**0.13**	**0.13**	**0.47**	**62.4**	**0.50**	**37.6**
			STDEV	**0.16**		**0.14**		**0.07**		**0.04**		**0.03**		**2.8**		**2.8**
TT Control	Post	P	Subject 3	1.22		1.25		0.64		0.62		0.17		65.2		34.8
			Subject 14	1.14		1.12		0.60		0.59		0.13		60.3		39.7
			Subject 16	1.27		1.24		0.67		0.64		0.07		63.8		36.2
			AVERAGE	**1.21**		**1.20**		**0.64**		**0.61**		**0.13**		**63.1**		**36.9**
			STDEV	**0.07**		**0.08**		**0.03**		**0.02**		**0.05**		**2.5**		**2.5**
TT Training	Post	P	Subject 5	1.10		1.17		0.51		0.66		0.06		59.2		40.8
			Subject 6	1.18		1.22		0.60		0.65		0.16		66.6		33.4
			Subject 11	1.19		1.26		0.59		0.67		0.07		62.5		37.5
			Subject 12	1.46		1.38		0.76		0.67		0.12		64.2		35.8
			AVERAGE	**1.23**	**0.84**	**1.26**	**0.42**	**0.62**	**0.74**	**0.66**	**0.01**	**0.10**	**0.57**	**63.1**	**1.00**	**36.9**
			STDEV	**0.16**		**0.09**		**0.10**		**0.01**		**0.05**		**3.1**		**3.1**
TF Control	Pre	P	Subject 1	1.19		1.21		0.60		0.65		0.13		60.4		39.6
			Subject 2	1.32		1.32		0.65		0.72		0.19		62.5		37.5
			Subject 4	1.27		1.41		0.67		0.77		0.18		61.2		38.8
			Subject 9	1.13		1.20		0.63		0.71		0.13		62.4		37.6
			Subject 10	1.34		1.34		0.66		0.70		0.16		65.3		34.7
			AVERAGE	**1.25**		**1.30**		**0.64**		**0.71**		**0.16**		**62.4**		**37.6**
			STDEV	**0.09**		**0.09**		**0.03**		**0.04**		**0.03**		**1.9**		**1.9**
TF Training	Pre	P	Subject 7	1.26		1.24		0.68		0.65		0.09		63.9		36.1
			Subject 8	1.23		1.19		0.68		0.65		0.19		64.8		35.2
			Subject 15	1.31		1.35		0.70		0.69		0.12		66.7		33.3
			AVERAGE	**1.26**	**0.80**	**1.26**	**0.62**	**0.69**	**0.03**	**0.66**	**0.13**	**0.14**	**0.44**	**65.2**	**0.07**	**34.8**
			STDEV	**0.04**		**0.08**		**0.01**		**0.02**		**0.05**		**1.4**		**1.4**
TF Control	Post	P	Subject 1	1.21		1.20		0.60		0.65		0.15		59.7		40.3
			Subject 2	1.35		1.37		0.67		0.72		0.15		62.8		37.2
			Subject 4	1.33		1.31		0.64		0.73		0.18		58.0		42.0
			Subject 9	1.19		1.20		0.65		0.72		0.18		61.5		38.5
			Subject 10	1.30		1.38		0.63		0.73		0.17		64.1		35.9
			AVERAGE	**1.28**		**1.29**		**0.64**		**0.71**		**0.16**		**61.2**		**38.8**
			STDEV	**0.07**		**0.09**		**0.03**		**0.03**		**0.02**		**2.4**		**2.4**
TF Training	Post	P	Subject 7	1.29		1.28		0.66		0.69		0.09		61.1		38.9
			Subject 8	1.23		1.25		0.74		0.68		0.18		64.7		35.3
			Subject 15	1.32		1.35		0.69		0.70		0.12		66.2		33.8
			AVERAGE	**1.28**	**0.91**	**1.29**	**0.97**	**0.70**	**0.04**	**0.69**	**0.37**	**0.13**	**0.17**	**64.0**	**0.18**	**36.0**
			STDEV	**0.05**		**0.05**		**0.04**		**0.01**		**0.05**		**2.6**		**2.6**

Table C.4a: *Spatiotemporal Results from the Non-runners, Pre- & Post- Testing. T-test btw groups*

Non-Runners			Norm Stride Length (m)	T-TEST	Avg Stride Time (s)	T-TEST	Norm Step Length (m)	T-TEST	Avg Step Time (s)	T-TEST	Avg Step Width (m)	T-TEST	Avg Stance Time (%GC)	T-TEST	Avg Swing Time (%GC)	T-TEST
Pre	I	Subject 1	0.73		1.20		0.36		0.55		0.15		68.8		31.2	
		Subject 2	0.74		1.36		0.37		0.63		0.20		68.8		31.2	
		Subject 3	0.74		1.16		0.35		0.61		0.10		65.1		34.9	
		Subject 4	0.71		1.41		0.34		0.65		0.19		70.4		29.6	
		Subject 5	0.55		1.13		0.30		0.49		0.07		72.7		27.3	
		Subject 9	0.66		1.20		0.30		0.48		0.15		70.0		30.0	
		Subject 10	0.71		1.35		0.36		0.65		0.16		68.4		31.6	
		Subject 14	0.66		1.14		0.29		0.55		0.12		66.2		33.8	
		Subject 16	0.77		1.27		0.37		0.63		0.09		64.4		35.6	
		AVERAGE	**0.70**		**1.25**		**0.34**		**0.58**		**0.14**		**68.3**		**31.7**	
		STDEV	**0.07**		**0.10**		**0.03**		**0.07**		**0.04**		**2.7**		**2.7**	
Post	I	Subject 1	0.74		1.20		0.37		0.55		0.16		68.6		31.4	
		Subject 2	0.76		1.37		0.39		0.65		0.14		67.4		32.6	
		Subject 3	0.73		1.25		0.35		0.63		0.07		66.0		34.0	
		Subject 4	0.75		1.30		0.39		0.57		0.17		69.1		30.9	
		Subject 5	0.56		1.17		0.31		0.51		0.09		70.8		29.2	
		Subject 9	0.70		1.20		0.32		0.49		0.15		70.3		29.7	
		Subject 10	0.69		1.38		0.36		0.66		0.17		69.5		30.5	
		Subject 14	0.67		1.12		0.32		0.52		0.12		67.6		32.4	
		Subject 16	0.77		1.27		0.37		0.63		0.09		64.4		35.6	
		AVERAGE	**0.71**	**0.07**	**1.25**	**0.38**	**0.35**	**0.02**	**0.58**	**0.43**	**0.13**	**0.14**	**68.2**	**0.38**	**31.8**	**0.38**
		STDEV	**0.07**		**0.09**		**0.03**		**0.07**		**0.04**		**2.1**		**2.1**	
Pre	P	Subject 1	0.73		1.21		0.37		0.65		0.13		60.4		39.6	
		Subject 2	0.74		1.32		0.37		0.72		0.19		62.5		37.5	
		Subject 3	0.74		1.19		0.38		0.56		0.09		64.7		35.3	
		Subject 4	0.71		1.41		0.37		0.77		0.18		61.2		38.8	
		Subject 5	0.55		1.12		0.26		0.64		0.12		60.6		39.4	
		Subject 9	0.67		1.20		0.37		0.71		0.13		62.4		37.6	
		Subject 10	0.71		1.34		0.35		0.70		0.16		65.3		34.7	
		Subject 14	0.65		1.14		0.36		0.60		0.13		62.8		37.2	
		Subject 16	0.77		1.27		0.41		0.65		0.11		63.5		36.5	
		AVERAGE	**0.70**		**1.24**		**0.36**		**0.67**		**0.14**		**62.6**		**37.4**	
		STDEV	**0.07**		**0.10**		**0.04**		**0.06**		**0.03**		**1.7**		**1.7**	
Post	P	Subject 1	0.74		1.20		0.37		0.65		0.15		59.7		40.3	
		Subject 2	0.76		1.37		0.38		0.72		0.15		62.8		37.2	
		Subject 3	0.72		1.25		0.38		0.62		0.17		65.2		34.8	
		Subject 4	0.74		1.31		0.36		0.73		0.18		58.0		42.0	
		Subject 5	0.56		1.17		0.26		0.66		0.06		59.2		40.8	
		Subject 9	0.71		1.20		0.38		0.72		0.18		61.5		38.5	
		Subject 10	0.69		1.38		0.33		0.73		0.17		64.1		35.9	
		Subject 14	0.67		1.12		0.35		0.59		0.13		60.3		39.7	
		Subject 16	0.75		1.24		0.39		0.64		0.07		63.8		36.2	
		AVERAGE	**0.70**	**0.18**	**1.25**	**0.40**	**0.36**	**0.11**	**0.67**	**0.29**	**0.14**	**0.44**	**61.6**	**0.03**	**38.4**	**0.03**
		STDEV	**0.06**		**0.09**		**0.04**		**0.05**		**0.05**		**2.5**		**2.5**	

Table C.4b: *Spatiotemporal Results from Runners, Pre- & Post- Testing. T-test btw groups*

Runners																
Pre	I	Subject 6	0.69		1.17		0.34		0.56		0.15		71.1		28.9	
		Subject 7	0.73		1.27		0.35		0.64		0.06		65.7		34.3	
		Subject 8	0.63		1.20		0.28		0.55		0.19		68.3		31.7	
		Subject 11	0.72		1.30		0.36		0.59		0.09		66.1		33.9	
		Subject 12	0.74		1.42		0.38		0.73		0.08		63.8		36.2	
		Subject 15	0.74		1.37		0.34		0.68		0.13		68.1		31.9	
		AVERAGE	**0.71**		**1.29**		**0.34**		**0.62**		**0.11**		**67.2**		**32.8**	
		STDEV	**0.04**		**0.10**		**0.04**		**0.07**		**0.05**		**2.6**		**2.6**	
Post	I	Subject 6	0.72		1.22		0.35		0.57		0.17		69.5		30.5	
		Subject 7	0.71		1.29		0.35		0.61		0.06		67.7		32.3	
		Subject 8	0.64		1.28		0.27		0.60		0.19		67.8		32.2	
		Subject 11	0.72		1.25		0.36		0.59		0.09		67.8		32.2	
		Subject 12	0.76		1.40		0.38		0.74		0.11		63.0		37.0	
		Subject 15	0.73		1.38		0.36		0.66		0.14		69.3		30.7	
		AVERAGE	**0.71**	**0.30**	**1.30**	**0.21**	**0.34**	**0.45**	**0.63**	**0.42**	**0.13**	**0.03**	**67.5**	**0.30**	**32.5**	**0.30**
		STDEV	**0.04**		**0.07**		**0.04**		**0.06**		**0.05**		**2.4**		**2.4**	
Pre	P	Subject 6	0.69		1.17		0.35		0.62		0.14		66.6		33.4	
		Subject 7	0.70		1.24		0.38		0.65		0.09		63.9		36.1	
		Subject 8	0.63		1.19		0.35		0.65		0.19		64.8		35.2	
		Subject 11	0.72		1.28		0.35		0.69		0.08		61.0		39.0	
		Subject 12	0.76		1.43		0.36		0.70		0.16		61.6		38.4	
		Subject 15	0.73		1.35		0.39		0.69		0.12		66.7		33.3	
		AVERAGE	**0.70**		**1.28**		**0.37**		**0.67**		**0.13**		**64.1**		**35.9**	
		STDEV	**0.04**		**0.10**		**0.02**		**0.03**		**0.04**		**2.4**		**2.4**	
Post	P	Subject 6	0.72		1.22		0.37		0.65		0.16		66.6		33.4	
		Subject 7	0.72		1.28		0.37		0.69		0.09		61.1		38.9	
		Subject 8	0.63		1.25		0.38		0.68		0.18		64.7		35.3	
		Subject 11	0.71		1.26		0.35		0.67		0.07		62.5		37.5	
		Subject 12	0.76		1.38		0.40		0.67		0.12		64.2		35.8	
		Subject 15	0.74		1.35		0.38		0.70		0.12		66.2		33.8	
		AVERAGE	**0.71**	**0.06**	**1.29**	**0.25**	**0.37**	**0.14**	**0.68**	**0.23**	**0.12**	**0.22**	**64.2**	**0.45**	**35.8**	**0.45**
		STDEV	**0.04**		**0.06**		**0.02**		**0.02**		**0.04**		**2.1**		**2.1**	

Table C.5a: *Runners compared to Non-runners, pre-trials. T-test btw groups*

				Avg Stride Length (m)	T-TEST	Avg Stride Time (s)	T-TEST	Avg Step Length (m)	T-TEST	Avg Step Time (s)	T-TEST	Avg Step Width (m)	T-TEST	Avg StanceTime (%GC)	T-TEST	Avg SwingTime	T-TEST
			Subject 1	1.19		1.20		0.59		0.55		0.15		68.8		31.2	
			Subject 2	1.32		1.36		0.66		0.63		0.20		68.8		31.2	
			Subject 3	1.24		1.16		0.59		0.61		0.10		65.1		34.9	
			Subject 4	1.27		1.41		0.60		0.65		0.19		70.4		29.6	
			Subject 5	1.08		1.13		0.58		0.49		0.07		72.7		27.3	
NR	Pre	I	Subject 9	1.11		1.20		0.50		0.48		0.15		70.0		30.0	
			Subject 10	1.35		1.35		0.69		0.65		0.16		68.4		31.6	
			Subject 14	1.12		1.14		0.50		0.55		0.12		66.2		33.8	
			Subject 16	1.31		1.27		0.63		0.63		0.09		64.4		35.6	
			AVERAGE	**1.22**		**1.25**		**0.59**		**0.58**		**0.14**		**68.3**		**31.7**	
			STDEV	**0.10**		**0.10**		**0.06**		**0.07**		**0.04**		**2.7**		**2.7**	
			Subject 6	1.14		1.17		0.56		0.56		0.15		71.1		28.9	
			Subject 7	1.32		1.27		0.64		0.64		0.06		65.7		34.3	
			Subject 8	1.22		1.20		0.54		0.55		0.19		68.3		31.7	
R	Pre	I	Subject 11	1.20		1.30		0.60		0.59		0.09		66.1		33.9	
			Subject 12	1.41		1.42		0.73		0.73		0.08		63.8		36.2	
			Subject 15	1.33		1.37		0.62		0.68		0.13		68.1		31.9	
			AVERAGE	**1.27**	**0.19**	**1.29**	**0.23**	**0.61**	**0.28**	**0.62**	**0.13**	**0.11**	**0.17**	**67.2**	**0.22**	**32.8**	**0.22**
			STDEV	**0.10**		**0.10**		**0.07**		**0.07**		**0.05**		**2.6**		**2.6**	
			Subject 1	1.19		1.21		0.60		0.65		0.13		60.4		39.6	
			Subject 2	1.32		1.32		0.65		0.72		0.19		62.5		37.5	
			Subject 3	1.25		1.19		0.65		0.56		0.09		64.7		35.3	
			Subject 4	1.27		1.41		0.67		0.77		0.18		61.2		38.8	
			Subject 5	1.08		1.12		0.52		0.64		0.12		60.6		39.4	
NR	Pre	P	Subject 9	1.13		1.20		0.63		0.71		0.13		62.4		37.6	
			Subject 10	1.34		1.34		0.66		0.70		0.16		65.3		34.7	
			Subject 14	1.11		1.14		0.62		0.60		0.13		62.8		37.2	
			Subject 16	1.31		1.27		0.69		0.65		0.11		63.5		36.5	
			AVERAGE	**1.22**		**1.24**		**0.63**		**0.67**		**0.14**		**62.6**		**37.4**	
			STDEV	**0.10**		**0.10**		**0.05**		**0.06**		**0.03**		**1.7**		**1.7**	
			Subject 6	1.14		1.17		0.58		0.62		0.14		66.6		33.4	
			Subject 7	1.26		1.24		0.68		0.65		0.09		63.9		36.1	
			Subject 8	1.23		1.19		0.68		0.65		0.19		64.8		35.2	
R	Pre	P	Subject 11	1.20		1.28		0.59		0.69		0.08		61.0		39.0	
			Subject 12	1.45		1.43		0.70		0.70		0.16		61.6		38.4	
			Subject 15	1.31		1.35		0.70		0.69		0.12		66.7		33.3	
			AVERAGE	**1.26**	**0.23**	**1.28**	**0.26**	**0.66**	**0.20**	**0.67**	**0.49**	**0.13**	**0.40**	**64.1**	**0.09**	**35.9**	**0.09**
			STDEV	**0.11**		**0.10**		**0.05**		**0.03**		**0.04**		**2.4**		**2.4**	

Table C.5b: *Runners compared to Non-runners, post-trials. T-test btw groups*

Group	Trial	Condition		Avg Stride Length (m)	T-TEST	Avg Stride Time (s)	T-TEST	Avg Step Length (m)	T-TEST	Avg Step Time (s)	T-TEST	Avg Step Width (m)	T-TEST	Avg StanceTime (%GC)	T-TEST	Avg SwingTime	T-TEST
NR	Post	I	Subject 1	1.21		1.20		0.61		0.55		0.16		68.6		31.4	
			Subject 2	1.36		1.37		0.69		0.65		0.14		67.4		32.6	
			Subject 3	1.23		1.25		0.59		0.63		0.07		66.0		34.0	
			Subject 4	1.35		1.30		0.70		0.57		0.17		69.1		30.9	
			Subject 5	1.09		1.17		0.60		0.51		0.09		70.8		29.2	
			Subject 9	1.17		1.20		0.54		0.49		0.15		70.3		29.7	
			Subject 10	1.30		1.38		0.68		0.66		0.17		69.5		30.5	
			Subject 14	1.14		1.12		0.55		0.52		0.12		67.6		32.4	
			Subject 16	1.31		1.27		0.63		0.63		0.09		64.4		35.6	
			AVERAGE	**1.24**		**1.25**		**0.62**		**0.58**		**0.13**		**68.2**		**31.8**	
			STDEV	**0.09**		**0.09**		**0.06**		**0.07**		**0.04**		**2.1**		**2.1**	
R	Post	I	Subject 6	1.19		1.22		0.58		0.57		0.17		69.5		30.5	
			Subject 7	1.27		1.29		0.63		0.61		0.06		67.7		32.3	
			Subject 8	1.25		1.28		0.52		0.60		0.19		67.8		32.2	
			Subject 11	1.20		1.25		0.60		0.59		0.09		67.8		32.2	
			Subject 12	1.44		1.40		0.72		0.74		0.11		63.0		37.0	
			Subject 15	1.31		1.38		0.64		0.66		0.14		69.3		30.7	
			AVERAGE	**1.28**	**0.24**	**1.30**	**0.12**	**0.61**	**0.42**	**0.63**	**0.10**	**0.13**	**0.50**	**67.5**	**0.29**	**32.5**	**0.29**
			STDEV	**0.09**		**0.07**		**0.07**		**0.06**		**0.05**		**2.4**		**2.4**	
NR	Post	P	Subject 1	1.21		1.20		0.60		0.65		0.15		59.7		40.3	
			Subject 2	1.35		1.37		0.67		0.72		0.15		62.8		37.2	
			Subject 3	1.22		1.25		0.64		0.62		0.17		65.2		34.8	
			Subject 4	1.33		1.31		0.64		0.73		0.18		58.0		42.0	
			Subject 5	1.10		1.17		0.51		0.66		0.06		59.2		40.8	
			Subject 9	1.19		1.20		0.65		0.72		0.18		61.5		38.5	
			Subject 10	1.30		1.38		0.63		0.73		0.17		64.1		35.9	
			Subject 14	1.14		1.12		0.60		0.59		0.13		60.3		39.7	
			Subject 16	1.27		1.24		0.67		0.64		0.07		63.8		36.2	
			AVERAGE	**1.23**		**1.25**		**0.62**		**0.67**		**0.14**		**61.6**		**38.4**	
			STDEV	**0.09**		**0.09**		**0.05**		**0.05**		**0.05**		**2.5**		**2.5**	
R	Post	P	Subject 6	1.18		1.22		0.60		0.65		0.16		66.6		33.4	
			Subject 7	1.29		1.28		0.66		0.69		0.09		61.1		38.9	
			Subject 8	1.23		1.25		0.74		0.68		0.18		64.7		35.3	
			Subject 11	1.19		1.26		0.59		0.67		0.07		62.5		37.5	
			Subject 12	1.46		1.38		0.76		0.67		0.12		64.2		35.8	
			Subject 15	1.32		1.35		0.69		0.70		0.12		66.2		33.8	
			AVERAGE	**1.28**	**0.19**	**1.29**	**0.17**	**0.67**	**0.06**	**0.68**	**0.42**	**0.12**	**0.27**	**64.2**	**0.03**	**35.8**	**0.03**
			STDEV	**0.10**		**0.06**		**0.07**		**0.02**		**0.04**		**2.1**		**2.1**	

Table C.6: *Spatiotemporal results from the single non-runner in the control group as compared to the remainder of the runners, both pre- and post- testing.*

			Average	SD	-1 SD	+1 SD	-2 SD	+2 SD	-3 SD	+3 SD	-4 SD	+4 SD	-5 SD	+5 SD	-6 SD	+6 SD	Subject 5
Norm Stride Length (m)	I	Pre	0.71	0.04	0.67	0.75	0.63	0.79	0.59	0.83	0.55	0.87	0.51	0.91	0.47	0.95	0.55
		Post	0.71	0.04	0.67	0.75	0.63	0.79	0.59	0.83	0.55	0.87	0.51	0.91	0.47	0.95	0.56
	P	Pre	0.7	0.04	0.66	0.74	0.62	0.78	0.58	0.82	0.54	0.86	0.50	0.90	0.46	0.94	0.55
		Post	0.71	0.04	0.67	0.75	0.63	0.79	0.59	0.83	0.55	0.87	0.51	0.91	0.47	0.95	0.56
Avg Stride Time (s)	I	Pre	1.29	0.1	1.19	1.39	1.09	1.49	0.99	1.59	0.89	1.69	0.79	1.79	0.69	1.89	1.13
		Post	1.3	0.07	1.23	1.37	1.16	1.44	1.09	1.51	1.02	1.58	0.95	1.65	0.88	1.72	1.17
	P	Pre	1.28	0.1	1.18	1.38	1.08	1.48	0.98	1.58	0.88	1.68	0.78	1.78	0.68	1.88	1.12
		Post	1.29	0.06	1.23	1.35	1.17	1.41	1.11	1.47	1.05	1.53	0.99	1.59	0.93	1.65	1.17
Norm Step Length (m)	I	Pre	0.34	0.04	0.30	0.38	0.26	0.42	0.22	0.46	0.18	0.50	0.14	0.54	0.10	0.58	0.30
		Post	0.34	0.04	0.30	0.38	0.26	0.42	0.22	0.46	0.18	0.50	0.14	0.54	0.10	0.58	0.31
	P	Pre	0.37	0.02	0.35	0.39	0.33	0.41	0.31	0.43	0.29	0.45	0.27	0.47	0.25	0.49	0.26
		Post	0.37	0.02	0.35	0.39	0.33	0.41	0.31	0.43	0.29	0.45	0.27	0.47	0.25	0.49	0.26
Avg Step Time (s)	I	Pre	0.62	0.07	0.55	0.69	0.48	0.76	0.41	0.83	0.34	0.90	0.27	0.97	0.20	1.04	0.49
		Post	0.63	0.06	0.57	0.69	0.51	0.75	0.45	0.81	0.39	0.87	0.33	0.93	0.27	0.99	0.51
	P	Pre	0.67	0.03	0.64	0.70	0.61	0.73	0.58	0.76	0.55	0.79	0.52	0.82	0.49	0.85	0.64
		Post	0.68	0.02	0.66	0.70	0.64	0.72	0.62	0.74	0.60	0.76	0.58	0.78	0.56	0.80	0.66
Avg Step Width (m)	I	Pre	0.11	0.05	0.06	0.16	0.01	0.21	-0.04	0.26	-0.09	0.31	-0.14	0.36	-0.19	0.41	0.07
		Post	0.13	0.05	0.08	0.18	0.03	0.23	-0.02	0.28	-0.07	0.33	-0.12	0.38	-0.17	0.43	0.09
	P	Pre	0.13	0.04	0.09	0.17	0.05	0.21	0.01	0.25	-0.03	0.29	-0.07	0.33	-0.11	0.37	0.12
		Post	0.12	0.04	0.08	0.16	0.04	0.20	0.00	0.24	-0.04	0.28	-0.08	0.32	-0.12	0.36	0.06
Avg Stance Time (%GC)	I	Pre	67.2	2.6	64.6	69.8	62.0	72.4	59.4	75.0	56.8	77.6	54.2	80.2	51.6	82.8	72.7
		Post	67.5	2.4	65.1	69.9	62.7	72.3	60.3	74.7	57.9	77.1	55.5	79.5	53.1	81.9	70.8
	P	Pre	64.1	2.4	61.7	66.5	59.3	68.9	56.9	71.3	54.5	73.7	52.1	76.1	49.7	78.5	60.6
		Post	64.2	2.1	62.1	66.3	60.0	68.4	57.9	70.5	55.8	72.6	53.7	74.7	51.6	76.8	59.2
Avg Swing Time (%GC)	I	Pre	32.8	2.6	30.2	35.4	27.6	38.0	25.0	40.6	22.4	43.2	19.8	45.8	17.2	48.4	27.3
		Post	32.5	2.4	30.1	34.9	27.7	37.3	25.3	39.7	22.9	42.1	20.5	44.5	18.1	46.9	29.2
	P	Pre	35.9	2.4	33.5	38.3	31.1	40.7	28.7	43.1	26.3	45.5	23.9	47.9	21.5	50.3	39.4
		Post	35.8	2.1	33.7	37.9	31.6	40.0	29.5	42.1	27.4	44.2	25.3	46.3	23.2	48.4	40.8

APPENDIX D: KINEMATIC PROFILES

Table D.1a: *Control groups' individual hip flexion ROM, paired t-tests by session, within side*

Transtibial Controls

Subject	Intact Side Pre	Intact Side Post	Intact Side T-TEST	Prosthetic Side Pre	Prosthetic Side Post	Prosthetic Side T-TEST
s003	40.3	54.8	0.058	47.0	52.7	0.422
	42.0	54.6		50.1	48.1	
	37.4	53.9		44.8	45.5	
	45.1	48.3		52.8	49.2	
	45.3	50.5		53.5	48.2	
	51.8	46.5		56.4	43.9	
	50.8	48.4		47.9	47.5	
	48.4	43.5		49.3	55.6	
	42.9	41.0		43.5	51.4	
	40.1	47.2		48.4	55.8	
s014	34.3	35.7	0.062	37.4	31.4	0.174
	37.2	37.0		31.5	32.1	
	40.2	37.9		31.5	38.9	
	37.2	37.8		34.6	39.3	
	40.1	35.2		30.4	31.8	
	37.7	35.9		34.3	35.6	
	39.2	36.6		33.6	31.7	
	40.0	38.4		32.7	35.7	
	37.5	34.6		30.7	32.0	
	35.2	37.6		31.9	31.3	
s016	40.9	41.5	0.097	38.8	43.5	0.004
	41.8	39.2		39.9	45.6	
	42.6	38.7		44.8	42.8	
	41.5	39.7		39.4	44.0	
	40.9	39.2		38.1	45.0	
	40.8	42.5		39.0	41.9	
	41.8	43.0		41.0	43.2	
	42.0	41.9		37.4	41.1	
	41.9	39.0		39.6	41.5	
	40.3	41.1		41.9	41.0	

Transfemoral Controls

Subject	Intact Side Pre	Intact Side Post	Intact Side T-TEST	Prosthetic Side Pre	Prosthetic Side Post	Prosthetic Side T-TEST
s001	41.9	48.8	0.000	48.5	43.5	0.013
	38.9	47.8		45.0	42.6	
	40.0	44.6		47.9	44.0	
	42.4	49.8		45.8	42.1	
	39.8	47.9		50.2	41.6	
	41.6	48.0		44.9	40.8	
	40.5	45.5		43.5	44.6	
	40.1	49.6		46.3	45.3	
	40.4	49.4		44.1	39.7	
	39.7	50.2		41.8	45.3	
s002	50.5	47.5	0.082	42.0	47.7	0.000
	49.5	47.4		43.2	49.4	
	48.9	46.1		43.1	48.6	
	47.7	47.0		45.1	48.4	
	47.4	45.2		42.5	49.2	
	48.7	50.2		43.0	50.1	
	45.3	50.2		43.6	50.1	
	47.7	45.9		41.2	47.6	
	50.3	46.8		43.2	45.3	
	46.8	44.4		42.3	47.8	
s004	31.3	39.9	0.000	46.0	42.5	0.171
	29.5	42.9		48.4	40.2	
	31.0	42.2		44.0	46.9	
	30.5	39.0		46.1	43.5	
	31.5	40.8		44.9	44.3	
	30.3	45.7		48.2	44.8	
	33.0	38.7		45.0	42.1	
	30.8	38.7		42.4	48.1	
	31.8	49.0		43.6	46.4	
	30.9	38.5		46.7	43.7	
s009	39.1	49.1	0.000	34.7	33.9	0.002
	35.9	48.0		37.1	36.7	
	35.0	52.0		34.9	33.3	
	31.8	48.3		36.0	34.8	
	34.5	56.2		43.7	37.6	
	35.9	54.5		39.5	37.6	
	37.9	54.1		43.5	37.7	
	39.3	54.7		44.3	34.2	
	37.8	55.1		43.2	37.5	
	29.8	51.8		38.1	33.6	
s010	45.6	51.2	0.000	42.4	32.9	0.017
	49.3	56.3		42.1	51.0	
	43.0	52.9		41.4	39.3	
	43.3	53.3		42.1	38.1	
	36.7	53.3		50.2	33.0	
	46.4	53.1		39.2	34.5	
	33.2	56.0		50.5	34.2	
	39.0	58.0		39.9	35.2	
	38.7	53.0		42.1	34.5	
	42.7	54.7		41.6	39.4	

Table D.1b: *Training groups' individual hip flexion ROM, paired t-tests by session, within side*

Transtibial Training

Subject	Intact Side Pre	Intact Side Post	Intact Side T-TEST	Prosthetic Side Pre	Prosthetic Side Post	Prosthetic Side T-TEST
s005	38.1	39.2	0.210	31.0	30.6	0.000
	46.3	42.9		29.0	37.6	
	41.4	43.7		28.0	29.9	
	44.8	40.5		26.9	33.5	
	41.7	42.7		26.0	31.5	
	44.5	41.8		23.7	34.9	
	40.9	42.4		29.5	34.0	
	36.0	47.5		29.9	35.4	
	35.4	44.6		27.7	31.9	
	46.0	43.7		25.1	32.9	
s006	39.1	40.4	0.326	39.7	42.1	0.015
	44.8	40.0		40.2	42.2	
	42.7	40.7		40.1	41.2	
	42.3	40.6		34.5	41.4	
	38.2	42.9		36.5	40.2	
	43.0	43.5		40.4	42.2	
	40.4	38.0		42.3	41.4	
	42.7	45.1		38.2	41.2	
	38.0	44.7		39.1	43.4	
	40.5	40.9		43.7	42.3	
s011	45.1	40.3	0.460	45.8	46.9	0.409
	47.3	45.6		44.0	48.4	
	44.0	42.2		48.6	44.1	
	45.1	42.3		53.1	49.8	
	42.9	44.4		47.7	53.1	
	43.5	47.2		45.1	44.8	
	41.6	47.7		46.7	46.1	
	45.8	42.1		45.9	48.0	
	43.0	48.7		45.9	59.8	
	45.2	44.2		51.4	48.1	
s012	37.7	53.3	0.000	49.1	55.4	0.829
	38.9	47.7		50.9	53.9	
	38.5	51.9		50.0	46.9	
	39.2	58.5		48.6	48.6	
	35.8	51.2		47.5	45.1	
	43.5	54.4		50.8	49.1	
	38.6	51.6		51.0	47.1	
	40.1	52.3		48.7	53.3	
	37.7	48.0		50.2	50.0	
	39.5	46.7		47.7	47.5	

Transfemoral Training

Subject	Intact Side Pre	Intact Side Post	Intact Side T-TEST	Prosthetic Side Pre	Prosthetic Side Post	Prosthetic Side T-TEST
s007	37.1	51.5	0.000	42.139	37.809	0.095
	35.2	54.2		42.455	41.030	
	29.6	48.0		32.466	36.394	
	39.8	47.6		36.270	37.939	
	36.4	47.5		35.350	36.729	
	42.5	47.1		35.225	36.528	
	40.1	61.0		36.838	37.418	
	37.9	48.4		36.547	38.430	
	37.6	46.3		36.694	38.060	
	38.9	46.4		34.983	43.281	
s008	31.3	47.5	0.211	40.177	32.897	0.430
	62.6	48.9		38.462	38.668	
	48.4	48.0		37.364	35.158	
	45.3	49.4		28.584	29.752	
	45.2	46.7		34.853	33.414	
	42.9	43.7		33.041	30.179	
	37.1	45.6		30.165	31.586	
	43.2	45.7		25.737	29.926	
	45.6	46.9		28.701	32.655	
	45.4	44.6		28.786	29.684	
s015	55.8	53.9	0.164	46.461	52.994	0.000
	55.8	51.0		46.461	53.103	
	54.4	52.4		43.957	51.689	
	51.4	56.1		44.281	48.172	
	54.8	60.1		41.116	51.536	
	51.8	55.4		43.446	47.587	
	50.7	55.7		42.503	43.103	
	53.3	54.9		40.593	50.864	
	49.8	-		42.295	46.667	
	57.5	-		38.987	54.872	

Table D.2: *Averaged hip flexion ROM paired t-tests within group, type and side by session*

		Intact Side							Prosthetic Side						
		Pre			Post				Pre			Post			
Group	Subject	min	max	Δ	min	max	Δ	T Test	min	max	Δ	min	max	Δ	T Test
TT Control	s003	-12.6	30.5	43.1	-21.3	26.9	48.3	0.404	-12.2	35.9	48.2	-20.0	28.2	48.2	0.141
	s014	-18.7	18.2	36.8	-10.0	25.2	35.1		-10.8	21.2	32.0	-7.1	25.6	32.7	
	s016	-15.5	24.8	40.3	-11.2	27.5	38.7		-12.5	26.9	39.4	-9.6	32.3	41.9	
TF Control	s001	-10.7	29.7	40.4	-14.8	32.4	47.2	0.024	-15.2	30.2	45.4	-14.8	27.8	42.6	0.230
	s002	-20.1	27.8	47.9	-17.5	28.9	46.4		-23.6	18.7	42.3	-26.8	21.1	47.8	
	s004	-2.6	28.0	30.6	-8.4	31.8	40.2		-10.9	34.0	45.0	-15.0	28.7	43.8	
	s009	-2.1	31.9	34.0	-14.9	36.3	51.2		-7.0	30.9	37.9	-6.1	29.1	35.2	
	s010	-9.5	31.0	40.5	-20.4	31.3	51.7		-12.4	29.4	41.8	-10.9	23.6	34.5	
TT Training	s005	-5.2	35.1	40.4	-1.8	39.9	41.7	0.179	-0.8	26.3	27.2	1.7	34.2	32.5	0.177
	s006	-18.1	21.9	40.0	-17.5	23.1	40.6		-8.2	30.5	38.8	-10.4	30.7	41.1	
	s011	-20.6	22.8	43.4	-13.5	28.7	42.2		-22.1	25.0	47.1	-15.7	30.1	45.9	
	s012	-5.4	33.0	38.4	-21.4	28.1	49.4		-9.2	39.2	48.4	-11.5	36.8	48.3	
TF Training	s007	-12.2	24.1	36.3	-19.9	28.3	48.1	0.156	-17.9	18.1	36.0	-20.8	17.1	37.8	0.085
	s008	-8.0	35.4	43.4	-19.7	26.1	45.8		-5.0	24.9	29.8	-9.4	22.0	31.4	
	s015	-21.4	30.6	52.1	-19.2	33.0	52.3		-19.4	23.2	42.6	-18.1	30.9	49.0	

Table D.3: *Individual hip flexion ROM paired t-tests within running ability, type and side by session*

Intact Side

	Subject	Pre min	Pre max	Pre difference	Post min	Post max	Post difference	T Test
Non-Runners	s001	-10.7	29.7	40.4	-14.8	32.4	47.2	0.02
	s002	-20.1	27.8	47.9	-17.5	28.9	46.4	
	s003	-12.6	30.5	43.1	-21.3	26.9	48.3	
	s004	-2.6	28.0	30.6	-8.4	31.8	40.2	
	s005	-5.2	35.1	40.4	-1.8	39.9	41.7	
	s009	-2.1	31.9	34.0	-14.9	36.3	51.2	
	s010	-9.5	31.0	40.5	-20.4	31.3	51.7	
	s014	-18.7	18.2	36.8	-10.0	25.2	35.1	
	s016	-15.5	24.8	40.3	-11.2	27.5	38.7	
Runners	s006	-18.1	21.9	40.0	-17.5	23.1	40.6	0.07
	s007	-12.2	24.1	36.3	-19.9	28.3	48.1	
	s008	-8.0	35.4	43.4	-19.7	26.1	45.8	
	s011	-20.6	22.8	43.4	-13.5	28.7	42.2	
	s012	-5.4	33.0	38.4	-21.4	28.1	49.4	
	s015	-21.4	30.6	52.1	-19.2	33.0	52.3	
		T-TEST	NR to R	0.16			0.24	

Prosthetic Side

	Subject	Pre min	Pre max	Pre difference	Post min	Post max	Post difference	T Test
Non-Runners	s001	-15.2	30.2	45.4	-14.8	27.8	42.6	0.50
	s002	-23.6	18.7	42.3	-26.8	21.1	47.8	
	s003	-12.2	35.9	48.2	-20.0	28.2	48.2	
	s004	-10.9	34.0	45.0	-15.0	28.7	43.8	
	s005	-0.8	26.3	27.2	1.7	34.2	32.5	
	s009	-7.0	30.9	37.9	-6.1	29.1	35.2	
	s010	-12.4	29.4	41.8	-10.9	23.6	34.5	
	s014	-10.8	21.2	32.0	-7.1	25.6	32.7	
	s016	-12.5	26.9	39.4	-9.6	32.3	41.9	
Runners	s006	-8.2	30.5	38.8	-10.4	30.7	41.1	0.08
	s007	-17.9	18.1	36.0	-20.8	17.1	37.8	
	s008	-5.0	24.9	29.8	-9.4	22.0	31.4	
	s011	-22.1	25.0	47.1	-15.7	30.1	45.9	
	s012	-9.2	39.2	48.4	-11.5	36.8	48.3	
	s015	-19.4	23.2	42.6	-18.1	30.9	49.0	
		T-TEST	NR to R	0.44			0.26	

Table D.4: *Training group non-runner vs. remaining runners hip flexion ROM*

		Average	SD	-1 SD	+1 SD	-2 SD	+2 SD	Subject 5
I	Pre	42.3	5.6	36.7	47.8	31.1	53.4	40.4
	Post	46.4	4.4	42.0	50.8	37.6	55.3	41.7
P	Pre	40.5	7.0	33.4	47.5	26.4	54.5	27.2
	Post	42.3	6.8	35.4	49.1	28.6	55.9	32.5

Table D.5a: *Control groups' individual pelvic COM ROM, paired t-test by session*

Transtibial Controls			
Subject	Pre	Post	T-TEST
s003	0.039	0.051	0.276
	0.046	0.050	
	0.042	0.043	
	0.052	0.048	
	0.048	0.038	
	0.066	0.038	
	0.047	0.046	
	0.048	0.041	
	0.036	0.039	
	0.043	0.050	
s014	0.045	0.034	0.010
	0.055	0.041	
	0.047	0.049	
	0.047	0.045	
	0.044	0.042	
	0.051	0.039	
	0.047	0.038	
	0.043	0.046	
	0.045	0.043	
	0.049	0.045	
s016	0.058	0.049	0.000
	0.054	0.047	
	0.054	0.044	
	0.048	0.038	
	0.052	0.041	
	0.053	0.044	
	0.050	0.043	
	0.054	0.037	
	0.051	0.046	
	0.056	0.051	

Transfemoral Controls			
Subject	Pre	Post	T-TEST
s001	0.051	0.061	0.000
	0.050	0.055	
	0.043	0.060	
	0.041	0.058	
	0.048	0.056	
	0.044	0.055	
	0.037	0.055	
	0.042	0.063	
	0.040	0.057	
	0.037	0.059	
s002	0.062	0.067	0.084
	0.081	0.072	
	0.076	0.074	
	0.078	0.079	
	0.067	0.069	
	0.079	0.066	
	0.068	0.066	
	0.070	0.065	
	0.067	0.067	
	0.068	0.068	
s004	0.062	0.052	0.376
	0.051	0.051	
	0.057	0.060	
	0.058	0.056	
	0.049	0.053	
	0.056	0.062	
	0.055	0.058	
	0.060	0.062	
	0.065	0.064	
	0.056	0.054	
s009	0.068	0.057	0.004
	0.056	0.064	
	0.042	0.076	
	0.049	0.064	
	0.062	0.074	
	0.061	0.071	
	0.060	0.074	
	0.068	0.077	
	0.052	0.069	
	0.061	0.072	
s010	0.057	0.057	0.344
	0.070	0.060	
	0.064	0.051	
	0.054	0.054	
	0.055	0.056	
	0.049	0.051	
	0.054	0.053	
	0.048	0.058	
	0.047	0.056	
	0.057	0.053	

Table D.5b: *Training groups' individual pelvic COM ROM, paired t-test by session*

Transtibial Training			
Subject	Pre	Post	T-TEST
s005	0.051	0.048	0.113
	0.041	0.051	
	0.052	0.045	
	0.048	0.048	
	0.046	0.045	
	0.043	0.055	
	0.051	0.053	
	0.040	0.056	
	0.055	0.051	
	0.044	0.053	
s006	0.040	0.044	0.041
	0.051	0.049	
	0.050	0.043	
	0.045	0.044	
	0.050	0.042	
	0.052	0.051	
	0.055	0.048	
	0.052	0.050	
	0.051	0.053	
	0.058	0.046	
s011	0.035	0.038	0.190
	0.044	0.050	
	0.045	0.043	
	0.043	0.045	
	0.040	0.044	
	0.036	0.052	
	0.041	0.043	
	0.047	0.041	
	0.048	0.042	
	0.044	0.043	
s012	0.053	0.061	0.012
	0.051	0.051	
	0.043	0.055	
	0.044	0.051	
	0.058	0.061	
	0.064	0.056	
	0.071	0.073	
	0.045	0.052	
	0.050	0.058	
	0.047	0.057	

Transfemoral Training			
Subject	Pre	Post	T-TEST
s007	0.056	0.065	0.105
	0.045	0.064	
	0.054	0.056	
	0.055	0.048	
	0.063	0.056	
	0.057	0.051	
	0.051	0.065	
	0.056	0.061	
	0.048	0.054	
	0.052	0.057	
s008	0.054	0.057	0.371
	0.054	0.069	
	0.056	0.060	
	0.048	0.057	
	0.059	0.055	
	0.062	0.042	
	0.057	0.054	
	0.053	0.052	
	0.056	0.058	
	0.051	0.056	
s015	0.049	0.053	0.002
	0.049	0.058	
	0.050	0.047	
	0.046	0.058	
	0.049	0.056	
	0.044	0.056	
	0.052	0.051	
	0.045	0.066	
	0.043	0.067	
	0.048	0.062	

Table D.6: *Pelvic COM ROM paired t-test within running ability and by session*

PELVIS ROM (M) SUMMARY

	Subject	Pre min	Pre max	Pre difference	Post min	Post max	Post difference	T Test
Non-Runners	s001	0.870	0.913	0.043	0.839	0.896	0.057	0.767
	s002	0.889	0.960	0.071	0.877	0.946	0.069	
	s003	0.836	0.880	0.044	0.817	0.859	0.042	
	s004	0.998	1.054	0.056	0.944	0.997	0.054	
	s005	1.030	1.076	0.046	0.978	1.025	0.048	
	s009	0.942	0.998	0.056	0.868	0.936	0.068	
	s010	1.036	1.088	0.053	0.994	1.047	0.053	
	s014	0.922	0.967	0.045	0.910	0.949	0.039	
	s016	0.892	0.943	0.051	0.889	0.931	0.043	
Runners	s006	0.840	0.888	0.049	0.888	0.933	0.046	0.715
	s007	0.963	1.013	0.050	0.912	0.967	0.054	
	s008	1.007	1.061	0.054	0.933	0.988	0.056	
	s011	1.036	1.088	0.053	0.823	0.864	0.042	
	s012	0.960	1.007	0.047	0.932	0.986	0.054	
	s015	0.931	0.977	0.045	0.886	0.940	0.054	
		T-TEST	NR to R	0.561			0.724	

Table D.7: *Training group non-runner pelvic COM ROM as compared to runners*

	Average	SD	-1 SD	+1 SD	-2 SD	+2 SD	Subject 5
Pre	0.050	0.003	0.047	0.053	0.044	0.056	0.046
Post	0.051	0.006	0.045	0.057	0.039	0.063	0.048

APPENDIX E: PIECEWISE LINEAR LENGTH NORMALIZATION DETAILS

Table E.1a: *Control Group PLLN gait event timings, paired t-test within type and side, by session*

Control Group

Transtibial			Loading Response	T-Test	Mid-Stance	T-Test	Terminal Stance	T-Test	Pre-Swing	T-Test	Swing	T-Test
Pre	I	Subject 3	13		17		19		16		35	
		Subject 14	14		16		22		14		34	
		Subject 16	14		19		18		13		36	
		AVERAGE	**13.7**		**17.3**		**19.7**		**14.3**		**35.0**	
		STDEV	**0.6**		**1.5**		**2.1**		**1.5**		**1.0**	
Post	I	Subject 3	14		16		19		17		34	
		Subject 14	13		20		20		15		32	
		Subject 16	15		22		14		14		35	
		AVERAGE	**14.00**	**0.33**	**19.33**	**0.16**	**17.67**	**0.11**	**15.33**	**0.23**	**33.67**	**0.03**
		STDEV	**1.00**		**3.06**		**3.21**		**1.53**		**1.53**	
Pre	P	Subject 3	16		19		17		13		35	
		Subject 14	14		18		16		15		37	
		Subject 16	14		19		17		14		36	
		AVERAGE	**14.7**		**18.7**		**16.7**		**14.0**		**36.0**	
		STDEV	**1.2**		**0.6**		**0.6**		**1.0**		**1.0**	
Post	P	Subject 3	17		17		17		14		35	
		Subject 14	15		17		15		13		40	
		Subject 16	14		23		13		14		36	
		AVERAGE	**15.33**	**0.09**	**19.00**	**0.44**	**15.00**	**0.15**	**13.67**	**0.37**	**37.00**	**0.21**
		STDEV	**1.53**		**3.46**		**2.00**		**0.58**		**2.65**	

Transfemoral			Loading Response	T-Test	Mid-Stance	T-Test	Terminal Stance	T-Test	Pre-Swing	T-Test	Swing	T-Test
Pre	I	Subject 1	14		23		17		15		31	
		Subject 2	17		20		17		15		31	
		Subject 4	16		23		16		15		30	
		Subject 9	22		8		30		11		30	
		Subject 10	16		19		17		17		31	
		AVERAGE	**17.0**		**18.6**		**19.4**		**14.6**		**30.6**	
		STDEV	**3.0**		**6.2**		**5.9**		**2.2**		**0.5**	
Post	I	Subject 1	14		18		22		14		32	
		Subject 2	15		20		18		15		32	
		Subject 4	13		23		20		13		31	
		Subject 9	21		14		25		10		30	
		Subject 10	17		20		16		17		30	
		AVERAGE	**16.0**	**0.12**	**19.0**	**0.42**	**20.2**	**0.34**	**13.8**	**0.05**	**31.0**	**0.19**
		STDEV	**3.2**		**3.3**		**3.5**		**2.6**		**1.0**	
Pre	P	Subject 1	15		16		15		14		40	
		Subject 2	15		16		15		17		37	
		Subject 4	16		22		7		16		39	
		Subject 9	10		22		8		22		38	
		Subject 10	16		13		20		16		35	
		AVERAGE	**14.4**		**17.8**		**13.0**		**17.0**		**37.8**	
		STDEV	**2.5**		**4.0**		**5.4**		**3.0**		**1.9**	
Post	P	Subject 1	14		13		19		14		40	
		Subject 2	15		18		15		15		37	
		Subject 4	13		19		12		14		42	
		Subject 9	10		23		7		21		39	
		Subject 10	17		13		17		17		36	
		AVERAGE	**13.8**	**0.21**	**17.2**	**0.30**	**14.0**	**0.27**	**16.2**	**0.12**	**38.8**	**0.07**
		STDEV	**2.6**		**4.3**		**4.7**		**2.9**		**2.4**	

Table E.1b: *Training Group PLLN gait event timings, paired t-test within type and side, by session*

Training Group

Transtibial			Loading Response	T-Test	Mid-Stance	T-Test	Terminal Stance	T-Test	Pre-Swing	T-Test	Swing	T-Test
Pre	I	Subject 5	17		23		18		15		27	
		Subject 6	18		14		20		19		29	
		Subject 11	17		17		20		12		34	
		Subject 12	11		19		19		15		36	
		AVERAGE	**15.8**		**18.3**		**19.3**		**15.3**		**31.5**	
		STDEV	**3.2**		**3.8**		**1.0**		**2.9**		**4.2**	
Post	I	Subject 5	16		22		19		14		29	
		Subject 6	20		14		20		16		30	
		Subject 11	15		15		23		15		32	
		Subject 12	11		20		17		15		37	
		AVERAGE	**15.5**	**0.39**	**17.8**	**0.25**	**19.8**	**0.33**	**15.0**	**0.43**	**32.0**	**0.43**
		STDEV	**3.7**		**3.9**		**2.5**		**0.8**		**3.6**	
Pre	P	Subject 5	15		16		13		17		39	
		Subject 6	18		18		12		19		33	
		Subject 11	14		14		17		16		39	
		Subject 12	13		19		19		11		38	
		AVERAGE	**15.0**		**16.8**		**15.3**		**15.8**		**37.3**	
		STDEV	**2.2**		**2.2**		**3.3**		**3.4**		**2.9**	
Post	P	Subject 5	14		15		14		16		41	
		Subject 6	17		18		12		20		33	
		Subject 11	15		14		18		15		38	
		Subject 12	15		22		16		11		36	
		AVERAGE	**15.3**	**0.38**	**17.3**	**0.30**	**15.0**	**0.40**	**15.5**	**0.32**	**37.0**	**0.39**
		STDEV	**1.3**		**3.6**		**2.6**		**3.7**		**3.4**	

Transfemoral			Loading Response	T-Test	Mid-Stance	T-Test	Terminal Stance	T-Test	Pre-Swing	T-Test	Swing	T-Test
Pre	I	Subject 7	13		19		19		15		34	
		Subject 8	18		17		19		14		32	
		Subject 15	17		20		14		17		32	
		AVERAGE	**16.0**		**18.7**		**17.3**		**15.3**		**32.7**	
		STDEV	**2.6**		**1.5**		**2.9**		**1.5**		**1.2**	
Post	I	Subject 7	15		18		20		15		32	
		Subject 8	17		16		20		15		32	
		Subject 15	17		19		15		18		31	
		AVERAGE	**16.3**	**0.37**	**17.7**	**0.23**	**18.3**	**0.35**	**16.0**	**0.32**	**31.7**	**0.13**
		STDEV	**1.2**		**1.5**		**2.9**		**1.7**		**0.6**	
Pre	P	Subject 7	16		20		15		13		36	
		Subject 8	14		27		5		19		35	
		Subject 15	18		19		14		17		33	
		AVERAGE	**16.0**		**22.0**		**11.3**		**16.3**		**34.7**	
		STDEV	**2.0**		**4.4**		**5.5**		**3.1**		**1.5**	
Post	P	Subject 7	15		17		15		14		39	
		Subject 8	15		26		7		17		35	
		Subject 15	17		17		14		18		34	
		AVERAGE	**15.7**	**0.33**	**20.0**	**0.04**	**12.0**	**0.21**	**16.3**	**0.50**	**36.0**	**0.13**
		STDEV	**1.2**		**5.2**		**4.4**		**2.1**		**2.6**	

Table E.2a: *Non-Runner PLLN gait event timings, paired t-test within side, by session*

Non-Runners			Loading Response	T-Test	Mid-Stance	T-Test	Terminal Stance	T-Test	Pre-Swing	T-Test	Swing	T-Test
		Subject 1	14		23		17		15		31	
		Subject 2	17		20		17		15		31	
		Subject 3	13		17		19		16		35	
		Subject 4	16		23		16		15		30	
		Subject 5	17		23		18		15		27	
Pre Trials	Intact Limb	Subject 9	22		8		30		11		30	
		Subject 10	16		19		17		17		31	
		Subject 14	14		16		22		14		34	
		Subject 16	14		19		18		13		36	
		AVERAGE	**15.9**		**18.7**		**19.3**		**14.6**		**31.7**	
		STDEV	**2.7**		**4.8**		**4.4**		**1.7**		**2.8**	
		Subject 1	14		18		22		14		32	
		Subject 2	15		20		18		15		32	
		Subject 3	14		16		19		17		34	
		Subject 4	13		23		20		13		31	
		Subject 5	16		22		19		14		29	
Post Trials	Intact Limb	Subject 9	21		14		25		10		30	
		Subject 10	17		20		16		17		30	
		Subject 14	13		20		20		15		32	
		Subject 16	15		22		14		14		35	
		AVERAGE	**15.3**	**0.28**	**19.4**	**0.49**	**19.2**	**0.92**	**14.3**	**0.56**	**31.7**	**1.00**
		STDEV	**2.5**		**3.0**		**3.2**		**2.1**		**1.9**	
		Subject 1	15		16		15		14		40	
		Subject 2	15		16		15		17		37	
		Subject 3	16		19		17		13		35	
		Subject 4	16		22		7		16		39	
		Subject 5										
Pre Trials	Prosthetic Limb	Subject 9	10		22		8		22		38	
		Subject 10	16		13		20		16		35	
		Subject 14	14		18		16		15		37	
		Subject 16	14		19		17		14		36	
		AVERAGE	**14.5**		**18.1**		**14.4**		**15.9**		**37.1**	
		STDEV	**2.0**		**3.1**		**4.5**		**2.8**		**1.8**	
		Subject 1	14		13		19		14		40	
		Subject 2	15		18		15		15		37	
		Subject 3	17		17		17		14		35	
		Subject 4	13		19		12		14		42	
		Subject 5	14		15		14		16		41	
Post Trials	Prosthetic Limb	Subject 9	10		23		7		21		39	
		Subject 10	17		13		17		17		36	
		Subject 14	15		17		15		13		40	
		Subject 16	14		23		13		14		36	
		AVERAGE	**14.3**	**0.80**	**17.6**	**0.78**	**14.3**	**1.00**	**15.3**	**0.22**	**38.4**	**0.07**
		STDEV	**2.1**		**3.7**		**3.5**		**2.4**		**2.5**	

Table E.2b: *Runner PLLN gait event timings, paired t-test within side, by session*

	Runners		Loading Response	T-Test	Mid-Stance	T-Test	Terminal Stance	T-Test	Pre-Swing	T-Test	Swing	T-Test
Pre Trials	Intact Limb	Subject 6	18		14		20		19		29	
		Subject 7	13		19		19		15		34	
		Subject 8	18		17		19		14		32	
		Subject 11	17		17		20		12		34	
		Subject 12	11		19		19		15		36	
		Subject 15	17		20		14		17		32	
		AVERAGE	**15.7**		**17.7**		**18.5**		**15.3**		**32.8**	
		STDEV	**2.9**		**2.2**		**2.3**		**2.4**		**2.4**	
Post Trials	Intact Limb	Subject 6	20		14		20		16		30	
		Subject 7	15		18		20		15		32	
		Subject 8	17		16		20		15		32	
		Subject 11	15		15		23		15		32	
		Subject 12	11		20		17		15		37	
		Subject 15	17		19		15		18		31	
		AVERAGE	**15.8**	**0.81**	**17.0**	**0.17**	**19.2**	**0.36**	**15.7**	**0.70**	**32.3**	**0.41**
		STDEV	**3.0**		**2.4**		**2.8**		**1.2**		**2.4**	
Pre Trials	Prosthetic Limb	Subject 6	18		18		12		19		33	
		Subject 7	16		20		15		13		36	
		Subject 8	14		27		5		19		35	
		Subject 11	14		14		17		16		39	
		Subject 12	13		19		19		11		38	
		Subject 15	18		19		14		17		33	
		AVERAGE	**15.5**		**19.5**		**13.7**		**15.8**		**35.7**	
		STDEV	**2.2**		**4.2**		**4.9**		**3.3**		**2.5**	
Post Trials	Prosthetic Limb	Subject 6	17		18		12		20		33	
		Subject 7	15		17		15		14		39	
		Subject 8	15		26		7		17		35	
		Subject 11	15		14		18		15		38	
		Subject 12	15		22		16		11		36	
		Subject 15	17		17		14		18		34	
		AVERAGE	**15.7**	**0.77**	**19.0**	**0.58**	**13.7**	**1.00**	**15.8**	**1.00**	**35.8**	**0.82**
		STDEV	**1.0**		**4.3**		**3.8**		**3.2**		**2.3**	

Table E.3: *PLLN gait event timings for single training group non-runners as compared to runners*

			Average	SD	-1 SD	+1 SD	-2 SD	+2 SD	-3 SD	+3 SD	Subject 5
Loading Response	I	Pre	15.7	2.9	12.8	18.6	9.9	21.5	7.0	24.4	17
		Post	15.8	3.0	12.8	18.8	9.8	21.8	6.8	24.8	16
	P	Pre	15.5	2.2	13.3	17.7	11.1	19.9	8.9	22.1	15
		Post	15.7	1.0	14.7	16.7	13.7	17.7	12.7	18.7	14
Mid-Stance	I	Pre	17.7	2.2	15.5	19.9	13.3	22.1	11.1	24.3	23
		Post	17.0	2.4	14.6	19.4	12.2	21.8	9.8	24.2	22
	P	Pre	19.5	4.2	15.3	23.7	11.1	27.9	6.9	32.1	16
		Post	19.0	4.3	14.7	23.3	10.4	27.6	6.1	31.9	15
Terminal Stance	I	Pre	18.5	2.3	16.2	20.8	13.9	23.1	11.6	25.4	18
		Post	19.2	2.8	16.4	22.0	13.6	24.8	10.8	27.6	19
	P	Pre	13.7	4.9	8.8	18.6	3.9	23.5	-1.0	28.4	13
		Post	13.7	3.8	9.9	17.5	6.1	21.3	2.3	25.1	14
Pre-Swing	I	Pre	15.3	2.4	12.9	17.7	10.5	20.1	8.1	22.5	15
		Post	15.7	1.2	14.5	16.9	13.3	18.1	12.1	19.3	14
	P	Pre	15.8	3.3	12.5	19.1	9.2	22.4	5.9	25.7	17
		Post	15.8	3.2	12.6	19.0	9.4	22.2	6.2	25.4	16
Swing	I	Pre	32.8	2.4	30.4	34.7	28.0	37.1	25.6	39.5	27
		Post	32.3	2.4	29.9	34.7	27.5	37.1	25.1	39.5	29
	P	Pre	35.7	2.5	33.2	38.2	30.7	40.7	28.2	43.2	39
		Post	35.8	2.3	33.5	38.1	31.2	40.4	28.9	42.7	41