The Effect of a Weighted Pack on the Gait Patterns of Transtibial Amputees

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Abstract

With the popularity of outdoor activities like hiking, the demands of certain types of employment, or being a student, an individual's ability to carry a load is an important mobility consideration. By understanding the changes to an individual's gait when supporting a backpack load, an individual's ability to carry heavy loads for prolonged periods could be improved. Most biomechanical studies have examined the changes in able-bodied gait when carrying a load. However, research is lacking on the effect of backpack loads on amputee gait patterns.

This project examined the effects of a backpack load on the gait patterns of unilateral transtibial amputees. Ten participants performed walking trials on four surfaces (level ground, uneven ground, walking up an incline, and walking down an incline), without a pack and with a pack. A total of 40 trials were collected per subject, with 10 trials collected on each surface. Three-dimensional motion data were collected with an eight-camera Vicon Motion Analysis system to describe limb motion as well as compare kinematic outcomes between tasks and conditions. Force platform data were collected during the level ground trials and used to calculate kinetic measures for both limbs. With the addition of the pack changes were seen on each surface, with different changes occurring to each limb. The ramp up surface created the most changes when comparing the two conditions. The only change seen across all four surfaces was a decrease in ankle dorsiflexion before push-off on the prosthetic limb. The two next most common changes were increases in knee and hip flexion during weight-acceptance.

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List of Abbreviations

3D Three-Dimensional

GRF Ground Reaction Force

ROM Range of Motion

PEQ Prosthesis Evaluation Questionnaire

RTL Rehabilitation Technology Lab

WOP Without a Pack

WP With a Pack

SD Standard Deviation

Test Variable Abbreviations

AA1 Ankle plantarflexion (weight acceptance)

AA2 Ankle dorsiflexion (before push-off)

AA3 Ankle plantarflexion (at push-off)

AAV1 Ankle angular velocity (dorsiflexion after foot-flat)

AAV2 Ankle angular velocity (dorsiflexion before push-off)

AAV3 Ankle angular velocity (plantarflexion at push-off)

KA1 Knee angle (weight acceptance)

KA2 Knee angle (before push-off)

KA3 Knee angle (swing)

KAV1 Knee angular velocity (weight acceptance)

KAV2 Knee angular velocity (swing flexion)

KAV3 Knee angular velocity (swing extension)

HA1 Hip angle (max extension at push-off)

HA2 Hip angle (max flexion at weight acceptance)

HA3 Hip adduction (push-off)

HA4 Hip abduction (swing)

HAV1 Hip angular velocity (max extension at push-off)

HAV2 Hip angular velocity (max flexion at weight acceptance)

HAV3 Hip adduction angular velocity (push-off)

HAV4 Hip abduction angular velocity (swing)

PR1 Pelvic tilt (range)

PR2 Pelvic tilt (range)

PR3 Pelvic axial rotation (range)

TR1 Trunk flexion (range)

TR2 Trunk abduction/adduction (range)

TR3 Trunk axial rotation (range)

PAV1 Pelvic tilt angular velocity (absolute maximum)

PAV2 Pelvic obliquity angular velocity (absolute maximum)

PAV3 Pelvic axial rotation angular velocity (absolute maximum)

TAV1 Trunk flexion angular velocity (absolute maximum)

TAV2 Trunk abduction/adduction angular velocity (absolute maximum)

TAV3 Trunk axial rotation angular velocity (absolute maximum)

AM1 Maximum ankle moment (dorsiflexion foot slap)

AM2 Maximum ankle moment (plantarflexion transition)

AP1 Absorption by dorsiflexors after heel contact.

AP2 Generation by dorsiflexors to pull the leg forward over the foot.

AP3 Absorption by plantar flexors as leg rotates forward over foot

AP4 Generation of energy by plantar flexors at push-off

KM1 Maximum knee extension moment (weight acceptance)

KM2 Maximum knee flexion moment (midstance)

KP1 Energy absorbed by knee extensors during weight acceptance

KP2 Energy generated by knee extensors as knee extends during mid-stance

KP3 Energy absorbed by knee extensors as knee flexes during late stance and early swing

HM1 Maximum hip extension moment (foot slap)

HM2 Maximum hip flexion moment (toe-off to early swing)

HP1 Energy generated by hip extensors as hip extends during weight acceptance

HP2 Energy absorbed by hip flexors in mid-stance as backward-rotating thigh decelerates

HP3 Energy generated by hip during late stance and early swing to accelerate the lower limb upward and forward

List of Definitions

Gait	The pattern of movement of the limbs during (human) locomotion.
Unilateral	Only affecting one side of the body.
Transtibial	Anything occurring across or involving the tibia.
Power	The rate at which work is performed.
Work	The amount of energy transferred by a force through a distance.
Moment (of force)	The tendency of a force to rotate or twist an object.
Kinematics	A branch of mechanics that describes the motion of bodies without regard for the forces that causes the motion.
Stance phase	The period during human gait after heel-strike and before foot-off where the foot is in contact with the ground.
Swing phase	There period after foot-off and before heel-strike where one foot is in the air.
Heel-strike	Initial contact with the ground by the foot. The heel strikes the floor and pronates to the ball of the foot.
Foot-off	The period just before the swing phase where the foot is used to propel the leg through the air. Normally referred to as toe-off however due to lack of a mobile ankle it is referred to as foot-off when amputees are subjects.
Cadence	The number of steps per minute.
Double-support	The period of time during human gait between the heel-strike of one foot and the foot-off of the opposite foot, where both feet are in contact with the ground.
Statures per second	The stride rate normalized for a participant’s height.

K-Level	A method used to determine the functional level of a transtibial amputee. • Functional level 0: The patient does not have the ability or potential to ambulate or transfer safely with or without assistance and a prosthesis does not enhance his/her quality of life or mobility. • Functional level 1: The patient has the ability or potential to use a prosthesis for transfers or ambulation on level surfaces at fixed cadence. Typical of the limited and unlimited household ambulator. • Functional level 2: The patient has the ability or potential for ambulation with the ability to traverse low level environmental barriers such as curbs, stairs, or uneven surfaces. Typical of the limited community ambulator. • Functional level 3: The patient has the ability or potential for ambulation with variable cadence. Typical of the community ambulator who has the ability to traverse most environmental barriers and may have vocational, therapeutic, or exercise activity that demands prosthetic utilization beyond simple locomotion. • Functional level 4: The patient has the ability or potential for prosthetic ambulation that exceeds basic ambulation skills, exhibiting high impact, stress, or energy levels. Typical of the prosthetic demands of the child, active adult, or athlete.
Pearson Correlation Coefficient	Moderate: correlation coefficient is between 0.40 and 0.69. High: correlation coefficient is between 0.70 and 0.89. Very High: correlation coefficient is between 0.90 and 1.00.

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Chapter 1. Introduction

Certain professions require the carrying of cumbersome loads. These professions, combined with the increasing popularity of hiking and other outdoor activities, have made an individual's load bearing ability an important mobility consideration. An understanding of how an individual's gait is altered when supporting a backpack load is important for improving the ability to effectively carry heavy loads for prolonged periods and minimizing the risk of injuries such as foot blisters, metatarsalgia, stress fractures, knee pain, lower back injuries, and shoulder traction injury [1].

As outlined in the subsequent section, many studies have been completed on gait adaptations due to backpack loads on able-bodied individuals. However, to our knowledge there has been no research on the changes in amputee gait while carrying a load. Certain activities, such as hiking, and professions, such as the military and postal delivery, require heavy load-bearing [2]. An understanding of prosthetic gait strategies while bearing such loads can be used to optimize rehabilitation strategies designed to improve mobility and enable individuals with amputations to accomplishing these tasks more easily. The question being investigated in this study is: how do people with unilateral transtibial amputations adapt their gait to changes in loads while walking on level ground, uneven ground, and inclines?

1.1 Rationale

The outcomes from this study have practical and clinical significance. Quantitative biomechanical outcomes from the backpack load tasks can be used to guide therapy, prosthesis configuration, and new prosthetic technology developments. These developments can positively affect a person's mobility in the community and thereby enhance their quality of life. The dataset from this study can be used as a comparison baseline to help guide future studies, research, and gait analysis. Other professions and hobbies that require load-bearing, such as postal workers, hikers, and students with amputations, may all benefit from clinical and industrial use of the study outcomes.

1.2 Objective

To understand the biomechanical differences between unloaded and loaded gait, in the form of a weighted backpack, on unilateral transtibial amputees across level ground, uneven ground, and sloped surfaces.

1.3 Null Hypotheses

1.3.1 Amputee and Able Bodied Groups

1. A backpack load will not produce significant changes in temporal-spatial parameters of an amputee's gait pattern.
2. A backpack load will not produce significant changes in ankle, knee, and hip angles when comparing amputee and able bodied gait.
3. A backpack load will not produce a significantly greater maximum ankle dorsiflexion moment during level ground walking.
4. A backpack load will not produce greater net joint powers during level ground walking. Specifically, HP3 and KP2 power bursts will not be greater than the unloaded position.

5. There will be no changes to gait and stability when comparing between surface changes.

1.3.2 Amputated and Intact Leg

1. The amputated leg with not produce significantly different joint angles when compared to the intact leg.

2. The hip extensor and knee flexor moments will not be significantly greater on the amputated leg when compared to the intact leg.

3. Hip power will not be significantly greater on the amputated leg to compensate for the lack of an ankle joint.

1.4 Assumptions

Assumptions are necessary in all experiments and it is important to recognize and acknowledge them beforehand. These assumptions are:

- All participants are familiar with the use of a backpack and do not need instruction on its operation, or be required to produce novel gait patterns.

- All amputations will create biomechanically similar movements regardless of the residual limb length, type of prosthesis, and socket orientation.

- All bodies are rigid bodies, and the backpack and torso create one rigid body.

- All participants are familiar with their prosthesis and have had it properly fitted.

1.5 Limitations

It is important to recognize the limitations within the study's experimental design. Since all participants were volunteers, the sample group may not represent the entire transtibial amputee population, leading to a potential sampling bias. By only recruiting volunteers, our sample may not be representative of the entire population. The study outcomes are only applicable to males with transtibial amputation, at the K4 functional level (i.e., the ability or potential for prosthetic ambulation that exceeds basic ambulation skills, exhibiting high impact, stress, or energy levels), and not to other populations. Considering that a K4 functional level was required to participate, it could be inferred that all potential participants were active individuals, and considering the high response rate, sampling bias was minimized.

Lastly, gym mats were used to simulate gait over uneven ground. While this approach has been used extensively for uneven ground gait training, the mats did not have the variable consistency that is typically found on exterior uneven surfaces. This simulation may be more reflective of soft ground.

Chapter 2. Literature Review

2.1 Able-Bodied Gait

Qualitative and quantitative descriptions of able-bodied gait are well established in the literature. The gait of able-bodied individuals can then be compared to gait altered by experimental design to determine differences. Gait is analyzed in terms of a cycle, which can be defined as the time from one foot-strike to the successive foot-strike of the same leg [3]. One walking cycle consists of two phases, stance phase and swing phase, and lasts approximately one second [4]. The stance phase usually lasts for 62% of the cycle and consists of the period between heel-strike and foot-off. Swing phase begins with foot-off, ends with heel-strike, and lasts for 38% of the gait cycle (Figure 1).

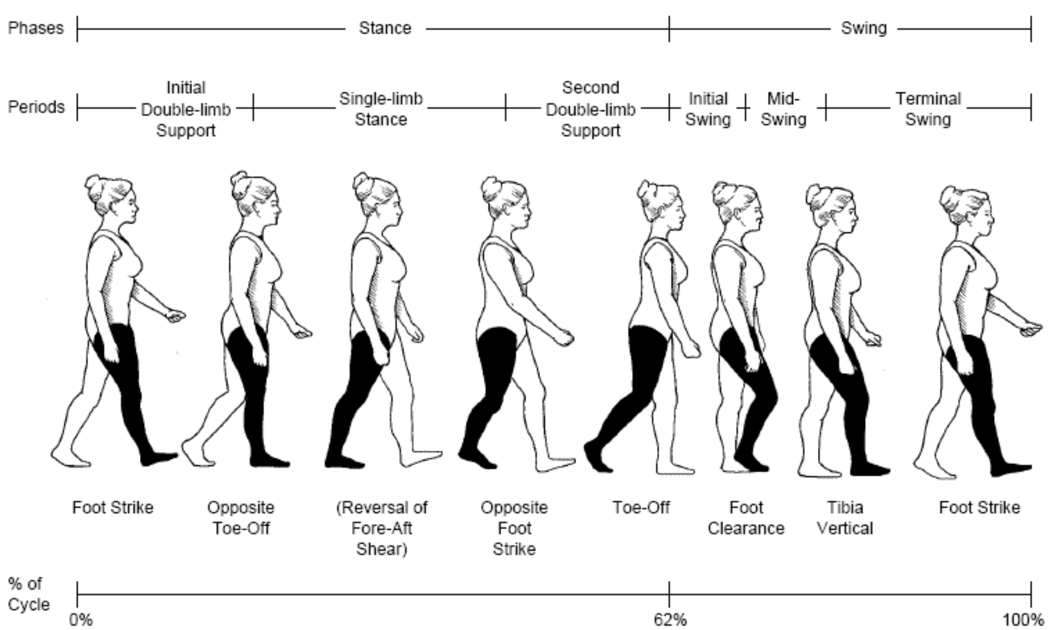

Figure 1: A complete gait cycle [3].

2.1.1 Temporal-spatial Parameters

Temporal-spatial parameters are common gait measurements because they provide easily obtainable information about movement patterns. Common measurements include cadence, walking velocity, step length, percentage of double-support time, percentage of single-support time, and length of swing phase [4]. Temporal-spatial parameters can change due to differing subject characteristics, such as height, sex, weight, and age [5].

Chambers and Sutherland [3] found that adults had an average cadence of 114 steps/min and an average step velocity of 1.23 m/s, which is in agreement with the range presented by Öberg, Karsznia, and Öberg [5] and Nadeau et al. [6] (Table 1).

Table 1: Able bodied temporal-spatial parameters reported by Nadeau et al. [6].

Variables	Level Walking
Speed (m/s)	1.16 (0.10)
Cadence (step/min)	105.4 (8.2)
Cycle duration (s)	1.145 (0.094)
Stride length (m)	1.32 (0.05)
Stance phase (%)	63.0 (1.0)
Swing phase (%)	37.0 (1.0)
Total double-support phase (%)	26.1 (2.0)

2.1.2 Kinematics

Kinematics is the study of motion without regards to its causes. One of the more commonly analyzed kinematic variables is joint angle. Sutherland, Olshen, Cooper, and Woo [7] outlined hip, knee, and ankle joint angle changes during gait. As shown in

Error! Not a valid bookmark self-reference., at heel-strike, the hip flexed to approximately 40 degrees, reached full extension shortly before foot-off, and flexed during swing. The knee flexed 9 degrees after heel-strike, followed by extension during the stance phase, and succeeded by a large flexion of approximately 63 degrees during the early swing phase. The ankle motion changed direction four times over the course of the gait cycle. Directly after heel-strike, the ankle plantarflexed until the foot was flat on the floor. This plantarflexion was followed by dorsiflexion until approximately forty percent of the gait cycle. A second plantarflexion occurs for another ten percent of the cycle, until foot-off, after which dorsiflexion occurs to allow for foot clearance into the swing phase.

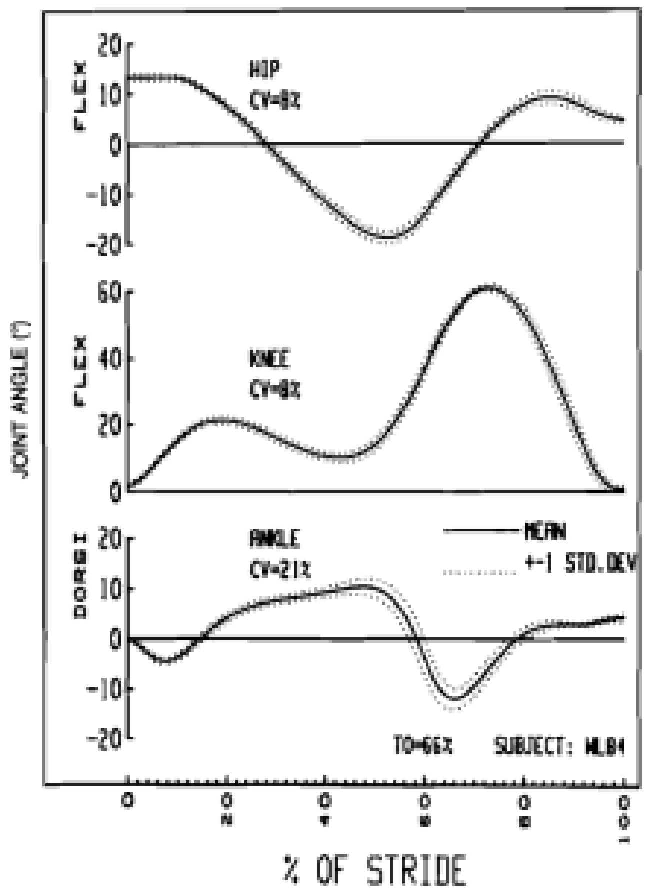

Figure 2: Ensemble averaged joint angles for one subject while walking [9].

2.1.3 Kinetics

One of the most popular ways to describe an individual's gait kinetics is to use the ground reaction forces (GRF) and the power bursts identified by Winter [9]. The vertical GRF during gait exhibits a double peak shape. The first peak coincides with weight acceptance, and the second peak occurs with foot-off. The horizontal GRF starts with a negative phase because the body slows down during weight acceptance and, in the second half of the curve, exhibits a positive phase indicating that the body is accelerating forward.

Table 2: Common descriptions for power bursts created by Winter et al. [8, 57].

Joint	Code	Peak Moment	Work	Phase	Description
Ankle	AP1	Dorsiflexor	negative	early stance	Absorption by dorsiflexors after heel contact. Some people do not exhibit AP1
	AP2	Dorsiflexor	negative	early stance	Generation by dorsiflexors to pull the leg forward over the foot. Some people do not exhibit AP2
	AP3	Plantarflexor	negative	mid stance	Absorption by plantar flexors as leg rotates forward over foot
	AP4	Plantarflexor	positive	late stance	Energy generation by plantar flexors at push-off
Knee	KP1	Extensor	negative	early stance	Energy absorbed by knee extensors during weight acceptance
	KP2	Extensor	positive	mid stance	Energy generated by knee extensors as knee extends during mid-stance
	KP3	Flexor	negative	late stance, early swing	Energy absorbed by knee extensors as knee flexes during late stance and early swing
	K4	Extensor	negative	late swing	Energy absorbed by knee flexors as knee extends late in swing
Hip	HP1	Extensor	positive	early stance	Energy generated by hip extensors as hip extends (hip flexion reduces) during weight acceptance
	HP2	Extensor	negative	mid stance	Energy absorbed by hip flexors in mid-stance as backward-rotating thigh is decelerated
	HP3	Flexor	positive	late stance, early swing	Energy generated by hip during late stance and early swing to accelerate the lower limb upward and forward

Winter et al. [8] outlined power bursts for the ankle, knee, and hip joints during able-bodied gait. Each burst was characterized by a net joint moment and net joint power (Table 2). Not all subjects will experience AP1 and AP2 power bursts. Also hip joint kinetics were extremely variable between subjects, and each individual power burst maybe more difficult to identify.

2.2 Load Bearing

The US Army recommends that soldiers carry a maximum of 22 kg during combat and 33 kg while marching [10]. This recommendation was supported by Underhill [11], who reported maximum load-bearing for the military, during all marching conditions, of 30-35 kg (Canadian), 32 kg (UK), and 33 kg (USA). The maximum weights recommended during fighting conditions were 10-15, 21 and 22 kg, respectively.

Pierrynowski, Winter, and Norman [12] suggested that the optimal load-bearing weight, based on metabolic measurements, is 25% of the subject's total body weight. Therefore, the 33 kg load would exceed this optimal level for most people weighing less than 130 kg, potentially limiting an individual's participation in certain activities. Biomechanical, assistive device, and load-carriage device factors become essential for optimizing these above-optimal loads that are required for military applications.

An individual's ability to bear a load is also affected by age and gender. The American Academy of Pediatrics recommended that backpack weight should not exceed 10-15% of overall body weight in young adolescents and children [13]. Korvessis et al. [14] found that young girls were six times more likely to experience thoracic back pain when carrying packs of the same weight as similarly aged boys. The researchers suggested that adolescent girls carry lighter backpacks to compensate for lower muscle strength, thereby reducing back pain.

The safe maximum weight for backpack loads is of concern because carrying too high a load can cause harm to the bearer. In schoolchildren, backpacks cause an increase in trunk inclination and a decrease in repositioning consistency [15]. During basic training, new military recruits and members of the infantry are very susceptible to overuse injury. An overuse injury can range from tendonitis to more serious diagnoses; such as, stress fractures, anterior compartment syndrome, and low back strain [16]. One of the most common factors for an overuse injury is carrying excessive loads [1, 17].

A wealth of research has been completed on load carriage physiological effects, but research is less extensive on the biomechanical effects of backpack load bearing [1, 18, 19]. The biomechanics research on the effects of load bearing has focused on kinematics and temporal-spatial parameters.

2.2.1 Temporal-spatial Parameters

Some of the most common gait outcomes for increased load-bearing were a shortened step length [1, 20, 21, 22], an increased stride rate or cadence [21, 22], an increased double stance time [1, 20, 21, 23], a decreased the swing phase [1, 21, 24], and no change in single stance time [1, 19, 21]. Vacheron et al. [22] and Birrell et al. [25] both noted an increase in the stance phase but made no distinction between double-support and single stance time. Lafiandra, Wagenaar, Holt, and Obusek [26] also noted a decrease in step length and an increase in stride rate between unloaded and loaded conditions, but did not use increasing loads in the experimental procedure.

Although there does seem to be a consensus in the literature for some gait changes in response to increasing loads, some discrepancies remain. The article by

Charteris [19] did not agree with any of the gait changes outlined in the previous paragraph, except the change in single stance time. Like Charteris, Atwells, Birrell, Hooper, and Mansfield [18] also reported initial differences during a lighter load condition but, as load increased, similar changes to the ones mentioned in the previous paragraph were seen. One of the main reasons for inconsistencies in the literature is that subjects typically used a self-selected walking speed. A self-selected speed allows for a natural gait pattern, subject comfort, and less chance that force plate targeting will occur. The article by Atwells [18] stated, in reference to an articles by Charteris [19] and Harmen et al. [27], "As load increases stride length normally decreases, increasing the period of double-support, so providing greater stability. This, however, is only seen at a fixed pace. With self-selected pacing such observations have not been as clear". Several reviews of load carriage also reported effects from determinants that can alter one's ability to bear cumbersome loads [1, 28]. These determinants included age, anthropometry, strength, training, body composition, gender, placement and dimensions of the load, biomechanical factors, climate, terrain, and gradient [18]. Although a general understanding exists of how able-bodied gait is changed when carrying a load; individuals with lower extremity amputations may have an altered ability to carry those same loads due to the above listed determinants (strength, body composition, biomechanical factors, etc.), which supports the need to gain a better understanding of prosthetic gait under these conditions.

2.2.2 Kinematics

An increase in knee and ankle joint angles has been noted as backpack load increases [18, 20]. Atwells et al. [18] noted an increase in maximum ankle joint angle at approximately 85% of stance phase, corresponding to foot-off, and an overall increase in ankle range of motion as load increased. However, both of these findings were not statistically significant when compared to an unweighted condition.

A significant increase in knee ROM was also found [18]. This increase was due to increased knee flexion during heel-strike and loading response (0-25% of stance time), and greater knee extension during foot-off. Lastly, maximum thigh angle and overall thigh range of motion were significant greater than the unweighted condition as load increased. The increase in thigh angle was due to increased hip flexion during heel-strike and an increase in hip extension during foot-off. Kinoshita [20] also found an increase in knee flexion during weight acceptance as load increased. Ghori and Luckwill [24] found an increase in maximum knee flexion as load increased and that this increase in knee flexion occurred earlier than unweighted trials due to the decrease in swing phase.

2.2.3 Kinetics

Studies that analyzed walking with a backpack load found similar kinetic outcomes. Both vertical and horizontal GRF [1, 2, 25, 29], and work and power in the vertical direction [29], increased as load increased. However, differences of opinion exist about how gait kinetics change as load increases. Tilbury-Davis [29] reported that these increased values were not significant when normalized for total mass. Knapik et al. [1] found the opposite, that the increase in GRF was not proportional to the increase in pack weight. This lack of complete understanding begins with able-bodied gait kinetic changes and extends to prosthetic gait. It is essential that we not only understand how an individual's gait is altered as load increases, but also why an individual's gait is altered by carriage loads.

2.3 Surfaces

Just as adding a load changes an individual's gait, the walking surface can also alter gait patterns. The three surfaces in this thesis are level ground, incline (Figure 3), and uneven ground (i.e., compliant foam, Figure 4). The research involving gait on uneven ground is not as prevalent as inclined walking and gaps in the literature are notable.

2.3.1.1 Inclined Walking Temporal-spatial Characteristics

Research on temporal-spatial characteristics across surfaces is somewhat limited and conflicting. Han et al. [30] reported that both step time and double-support duration increased, and velocity and cadence decreased, at inclines above eight percent. Stance duration increased at inclines above 16 percent and step length decreased at inclines over 24 percent. However, Leroux et al. [31] found that stride length and duration increased as incline increased and decreased when walking downhill. The proportion of stance and swing phase was not affected by incline. Redfern and DiPasquale [32] reported no changes in step length while walking downhill, until the incline was greater than 10 degrees, after which step length declined. The authors also found that step duration decreased when walking downhill. McIntosh et al. [33] found that cadence decreased and walking speed increased as incline increased while walking uphill. Lastly, Lay et al. [34] found no significant changes to stride length or stride duration when walking uphill or downhill.

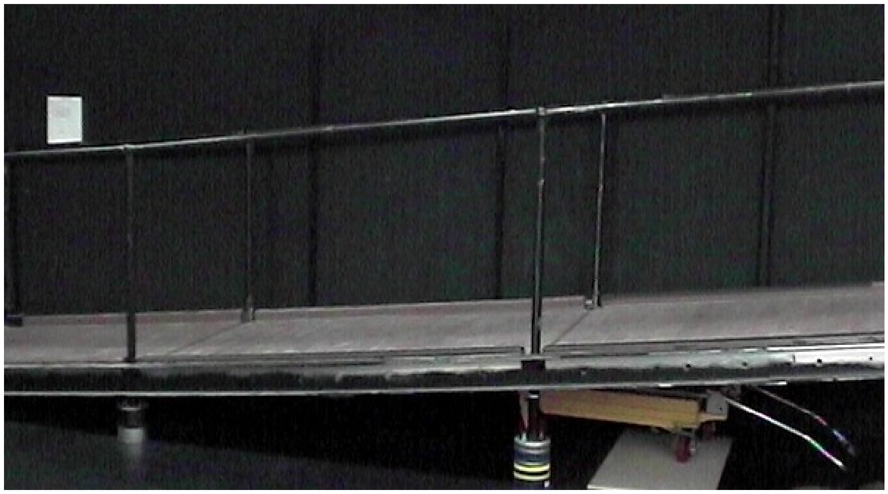

Figure 3: The inclined surface used in the thesis for ramp up and ramp down.

2.3.1.2 Inclined Walking Kinematics

Both Leroux [31] and Prentice et al. [35] noticed an increase in flexion from all three joints (hip, knee, ankle dorsiflexion) when walking uphill. Leroux [31] recorded an increase in flexion at all three joints from mid-stance to early swing and also noted a decrease in flexion while walking downhill from mid-swing to early stance. Prentice [35] noted an increase in flexion in all three joints from toe-off to foot contact. Han et al. [30] also found similar results where flexion increased at the hip, knee, and ankle at heel contact, mid-stance, and mid-swing as incline increased.

Lay et al. [34] found that the ankle was dorsiflexed for most of stance while walking uphill. The only angular changes at the ankle while walking downhill, when compared to level ground walking, were differences in peak magnitudes. Knee flexion increased at heel-strike during upslope walking, followed by increased knee extension at mid-stance to lift the body up the slope. Walking downhill produced greater knee flexion during stance in order to lower the body down the incline. The hip angles only varied from level ground walking during the maximum peaks of upslope gait. During down slope walking, hip flexion angle decreased during early stance and late swing, but increased during mid-stance.

Vrieling et al. [36] examined transtibial amputee gait while walking uphill and downhill. During uphill walking, knee flexion during early stance was increased in the non-affected limb to compensate for the shorter prosthetic limb length. Hip flexion at initial contact and swing, and knee flexion at initial contact, were greater on the prosthetic limb. Downhill walking created increased knee flexion during late stance and swing on the prosthetic limb. Decreased hip extension in late stance of the affected limb was also found during uphill and downhill walking.

2.3.2.1 Uneven Ground Temporal-spatial Parameters

When comparing gait on uneven ground to level ground, cadence [37, 38], walking velocity [37, 38], and step length [38, 39] decreased and step width [38, 39], step time [40], step length variability [39], and step width variability [40] increased. An increase in double-support time was also noted by Menant et al. [38]. Paysant et al. [41] also found that, when compared to controls, transtibial amputees exhibited a larger decrease in stride length when moving from asphalt to grass.

Figure 4: Foam mats used to simulate uneven ground in the thesis.

2.3.2.2 Uneven Ground Kinematics

Gait research is lacking on kinematic changes as surfaces become more irregular. No studies were found that outlined the kinematic changes that occur as the surface changes from level to uneven. One finding by Patel et al. [42] stated that participants exhibited more movements at the knee when moving from solid ground to foam, to increase postural stability. Marigold and Patla [43] also found that, as compliance increased (i.e., the surface became more irregular), knee flexion angle increased to preserve toe clearance.

2.4 Amputee Gait

Although there have been no studies performed on the effect of load-carriage by amputees, many studies have examined how prosthetic gait differs from able-bodied walking. Since the scope of this project is limited to unilateral transtibial amputees, this literature review will only cover unilateral transtibial amputee locomotion.

2.4.1 Temporal-spatial Parameters

The majority of amputee gait studies focus on either the differences from able-bodied controls or the differences between the unaffected and affected limbs. When compared to the unaffected limb, the amputated limb has a longer step length [47, 48], a shorter stance time [47, 48, 49, 50], a longer swing phase [47, 48], and a shorter step duration [48]. Others researchers found that amputees had a shorter single stance time than controls [44, 51]. The previous articles by Goujon [49], Grumillier [50], Kovac [47], and Isakov [48] did not make a distinction between single and double-support times; one stance time was used as the outcome variable.

When comparing amputee gait with able-bodied individuals, transtibial amputees typically walk at a slower velocity when self-selecting their speed [51, 52, 53], have a lower cadence, increased swing phase [47], and a decreased stance time [47, 50].

2.4.2 Kinematics

Joint angles during transtibial amputee gait differ from able-bodied controls and between limbs (Figure 5). Both Bateni [51] and Nolan [54] found that the intact ankle range of motion was greater than controls, with Bateni reporting increased dorsiflexion. Bateni [51] also found greater knee flexion in both amputated and non-amputated limbs. This is contradictory to the findings of Powers, Rao, and Perry [53] who reported that, during the initial 40 percent of the gait cycle, there was a significant decrease in knee flexion and no changes after 40 percent of gait. The non-amputated limb had greater hip extension and the amputated limb had greater maximum hip flexion angles during gait, when compared to controls [51].

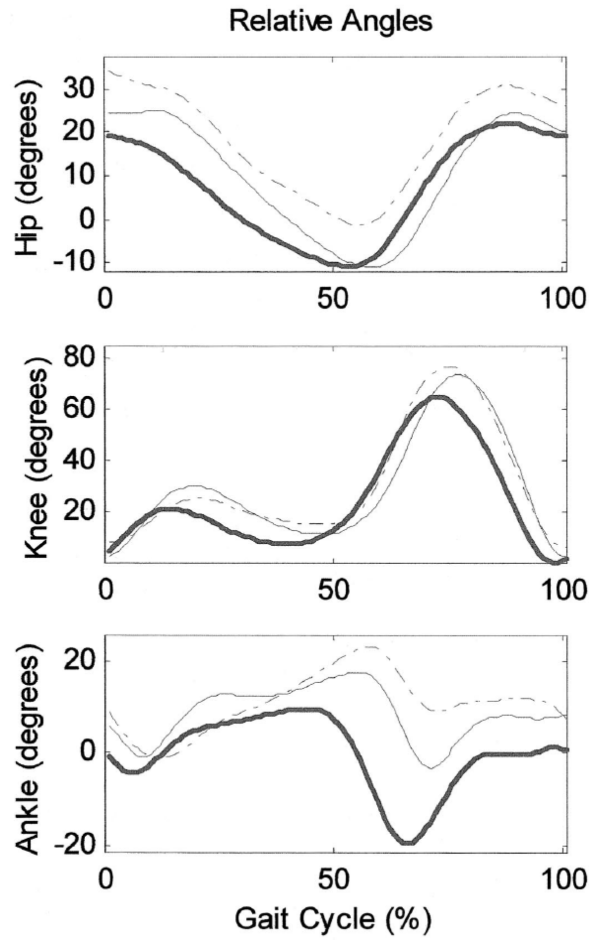

Figure 5: Joint angles for a single subject. The Grey dashed line = prosthetic limb, grey solid line = intact limb, black line = able bodied subject [30].

In their study of transtibial amputee gait, Bateni and Olney [51] recorded an increase in knee flexion during early stance on both limbs and a maximum hip flexion increase on the affected side, most likely due to an amputee's increased step length. The most obvious difference for amputees is the decreased ankle joint range of motion on the affected limb [51, 55]. Nolan [54] found that the ankle on the intact limb moved through a greater range of motion when compared to able-bodied subjects. The author also found a decrease in affected ankle joint range of motion, but that this range was dependant on prosthesis type. To enable stability during movement or standing, a prosthetic ankle is stiffer than an intact ankle (i.e., intact limb stiffens depending on the need, which cannot be accomplished with conventional prosthetic technology). Gait parameters have also been reported to be affected by the person's pain level [56].

2.4.3 Kinetics

The most common kinetics changes for transtibial prosthetic gait occur for GRF, joint moments, and joint powers. A common way to analyze joint moments and powers is to examine the distinct power bursts that were labeled by Winter et al. [8, 57] (Table 2, Figure 6).

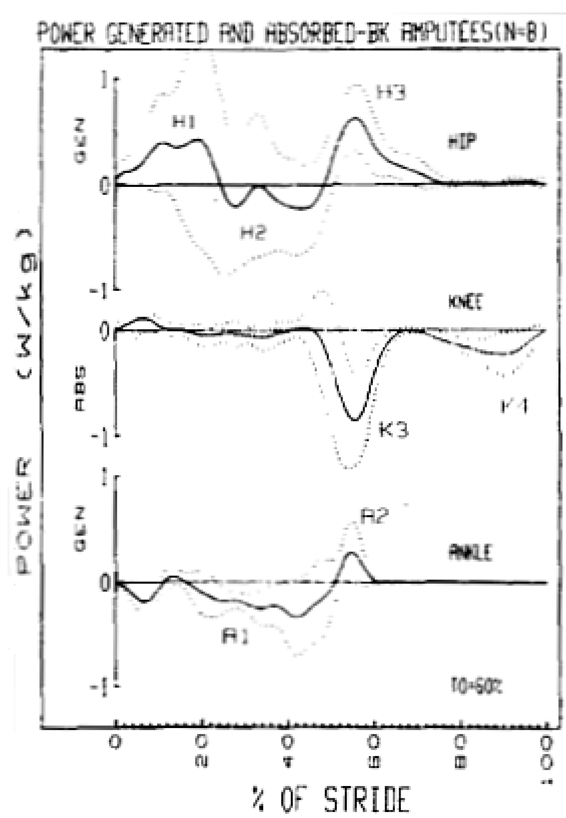

Figure 6: Ensemble averaged mechanical power curves for eight amputee trials [57].

In an article by Winter and Sienko [57], transtibial amputee subjects experienced longer ankle dorsiflexion moments for 18% of the stride, as compared to 6% in able-bodied participants, and a decreased plantarflexion moment because the centre of pressure moved towards the ball of the foot. This longer dorsiflexion moment was attributable to ankle joint rigidity, which also contributed to a longer time to foot-flat during weight acceptance. An able-bodied individual will have a greater plantarflexion moment, causing rapid plantarflexion and the AP2 power burst.

Knee moments were near zero during the first half of stance. All amputee subjects experienced an absence of the KP1 and KP2 power bursts during gait and therefore an absence of significant extensor moments. Lastly, the hip values for both moments and powers were highly variable, more so than values for the already variable able-bodied population. A general trend did show a stronger HP1 power burst, resulting from the hip extensors compensating for the lack of energy generation by the ankle plantar flexors. Conversely, Nolan and Lees [54] found that the intact limb had a significantly greater knee extensor moment than controls, possibly to control the rate of knee flexion at foot-off. Ground reaction forces on the affected limb were also reduced in the horizontal direction [44, 52], due to the lower propulsive forces from the prosthetic limb.

2.5 Instrumentation

2.5.1 Camera Based Systems

Camera based motion analysis systems are used in the field of biomechanics to capture three dimensional coordinate data (Figure 7). These systems can use markers or work as a marker free system, with passive marker based systems being the most common. For passive marker systems, cameras equipped with light emitting strobes are placed around the movement volume. The number of cameras and their placement is dependent upon the motion being analyzed. Reflective markers are placed at designated anatomical locations on the participant, with the number of markers and their placement depending upon the experimental design requirements. The strobe lights are reflected off the marker surface to produce high contrast images for the camera. Frames from multiple cameras are processed to obtain three dimensional marker coordinates. An example of a common camera based approach is the Vicon Motion System [58].

2.5.2 Force Plates

Force plates, or force platforms, are force transducers commonly used in gait analysis to record GRF forces applied to the plate, also known as the ground reaction force [59]. There are several different models of force plates, either containing strain gauges or piezoelectric transducers, with the most common coming from Bertec (Bertec Corp., Columbus, OH, USA), Kistler (Kistler Instrumente AG, Winterthur, Switzerland), and AMTI (Advanced Mechanical Technology, Inc., Watertown, MA, USA).

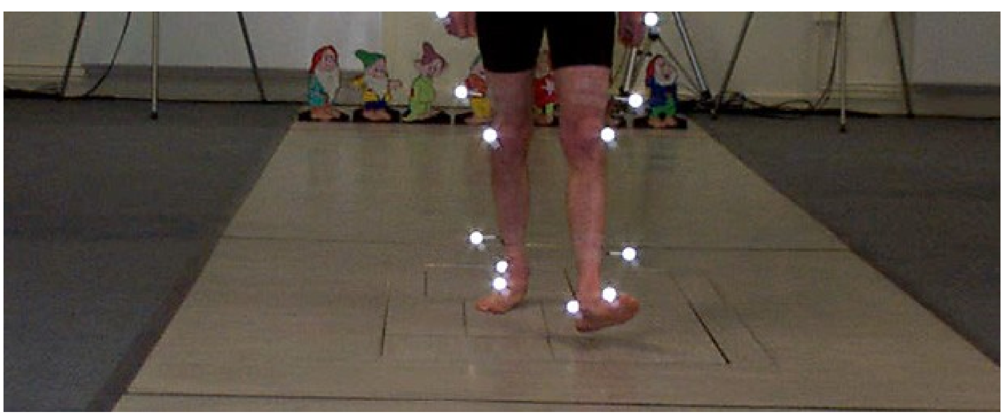

Figure 7: Camera data collection with reflective markers [58].

When using a force plate, the investigator must ensure that only one foot comes into contact with a plate because force plates output the sum of the forces in each plane, removing the ability to discern forces created by each foot. When the force plate is visible, a participant may alter their gait to ensure that they contact the plate, thereby creating experimental error known as targeting.

2.5.3 Prosthesis Evaluation Questionnaire (PEQ)

The prosthesis evaluation questionnaire is a self-administered questionnaire developed by Legro et al. [60] to evaluate a subject's prosthesis and his/her life with the prosthesis. The questionnaire employs a visual analogue scale where a response is marked on a 100 mm line and responses closer to the right are considered better. A score is calculated for each scale by summing the responses (0-100 for each response) and dividing the sum by the number of questions asked. The questionnaire consists of nine subscales: ambulation, appearance, frustration, perceived response, residual limb health, social burden, sounds, utility, and well-being. Each subscale is independent so scales pertinent to the research question can be selected. The PEQ has proven to be both reliable and valid [60, 61].

2.6 Gaps in the Literature

As displayed in literature review, gaps exist in the knowledge base on amputee gait with backpack loads. There is also limited knowledge on how backpack loads alter gait on different surfaces. This thesis addresses these gaps by increasing the knowledge base for loaded gait of transtibial amputees across four different surfaces.

Chapter 3. Methods

3.1 Subjects

A convenience sample of 10 male unilateral transtibial amputees was recruited through The Ottawa Hospital Rehabilitation Centre and the Canadian Forces. Only men were included in this study to control for gender differences that have been reported for load-carrying biomechanics [1, 21, 62].

Subjects must have used a prosthesis for at least one year, used their device on a daily basis, had a K-level of four (the ability or potential for prosthetic ambulation that exceeds basic ambulation skills, exhibiting high impact, stress, or energy levels), and had successfully completed a gait training program. Participants were excluded if they had a vascular amputation, medical conditions, or used medication that affected balance, locomotion, or limited backpack load-bearing capability.

Potential subjects were identified from health records at The Ottawa Hospital and Canadian Forces. A physiatrist reviewed the potential subject's medications, medical history, and K-level before a recruitment letter was sent to the person. A research assistant followed-up by telephone if a response was not received two weeks after the initial mailing.

Before testing, the project assistant explained the study's purpose and procedures with the participant and then the participant was asked to read and sign an informed consent form. A prosthetist assessed the person and their prosthesis to ensure that the prosthetic device functioned appropriately and that the residual limb was healthy. No prosthetic or limb issues were found for the population sample.

3.2 Protocol

All data collection occurred at the Rehabilitation Technology Lab (RTL) located at The Ottawa Hospital Rehabilitation Centre. Upon testing session arrival, participants were asked to complete a Prosthetic Evaluation Questionnaire (PEQ) to assess their current prosthetic status. Gender, age, weight, K-Level, affected side, cause of amputation, time since amputation, prosthetic components, and socket/suspension type were also recorded.

Subjects were fitted with a 24.5 kg weighted pack [63] and were given sufficient time to accommodate to the load before testing. Following the accommodation period, reflective markers were attached to the body for three-dimensional (3D) motion analysis, as described in section 3.3.

Participants completed each walking task without the pack (WOP) and with the pack (WP). Walking task order were randomized for each subject and participants completed the tasks at a self-selected pace. Participants wore tight fitting shorts and shirts to limit marker movement during data collection.

The four walking tasks were level ground, uneven ground, ramp ascent, and ramp descent. For each task, five trials were recorded for WP and five for WOP conditions (total of 40 trials: 20 WOP, 20 WP). For the variables that were tested in this experiment, five trials exceeded the number of trials required to obtain a reliability of at least 0.90 [64]. Adequate rest was provided between trials and participants were free to stop at any time. The task protocols were:

- **Level Ground Walking**: Participants walked at a self-selected pace along a level 8 m walkway with two force plates embedded in the floor at the halfway point. The starting point was selected such that each foot was able to contact the force platform without targeting.
- **Uneven Ground**: Participants walked at a self-selected pace along an 8 m walkway that was covered with medium density foam mats (maximum compression of approximately 8 cm) to simulate an uneven surface (Figure 10). Participants were asked to walk the entire length of the 8 m walkway. It should be noted that mats are a simulation of uneven ground.
- **Ramp Ascent**: Participants walked at a self-selected pace up a ramp with a 7 degree incline. Handrails were located at the top of the platform.
- **Ramp Descent**: Participants walked at a self-selected pace down a ramp with a 7 degree incline.

The ramp and mats were moved in and out of the testing area when required.

3.3 Biomechanical Measurement

Three-dimensional kinematics and kinetics were collected at 120 Hz for the lower limbs and torso using an eight-camera Vicon Motion Analysis system. Reflective markers were attached to the legs, and pelvis as shown in Figure 8 and Figure 9. Markers were also added to the torso, located on the clavicle, sternum, and right and left shoulders. The rear pelvis markers were removed due to occlusion from the backpack and two gluteal markers were added to replace the posterior pelvis markers. Also, foot marker plates were not used since the camera system had trouble distinguishing between individual markers on the plates. Ground reaction force data were collected during level ground walking trials from AMTI and Bertec force plates connected to the Vicon system.

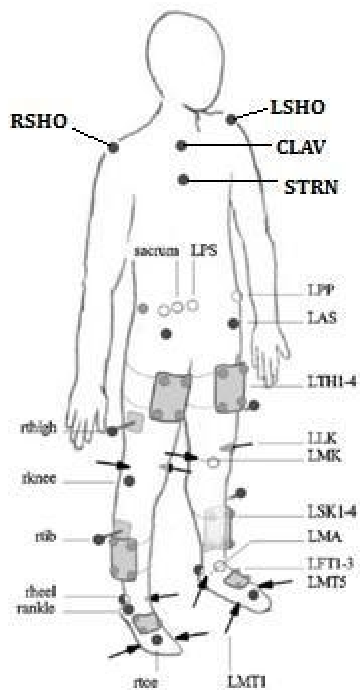

Figure 8: Marker placement [modified from 65].

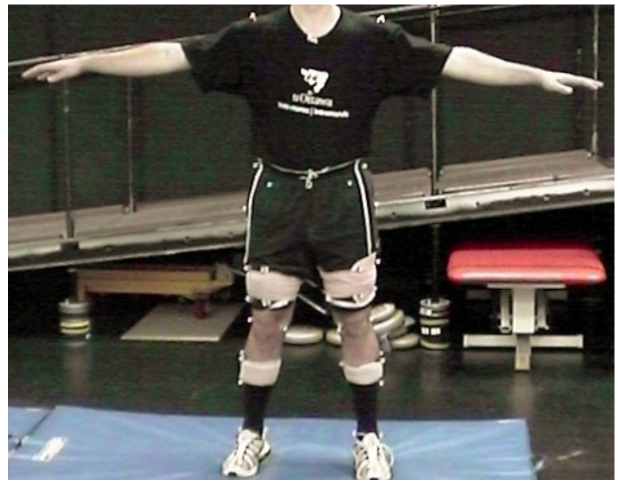

Figure 9: Marker set.

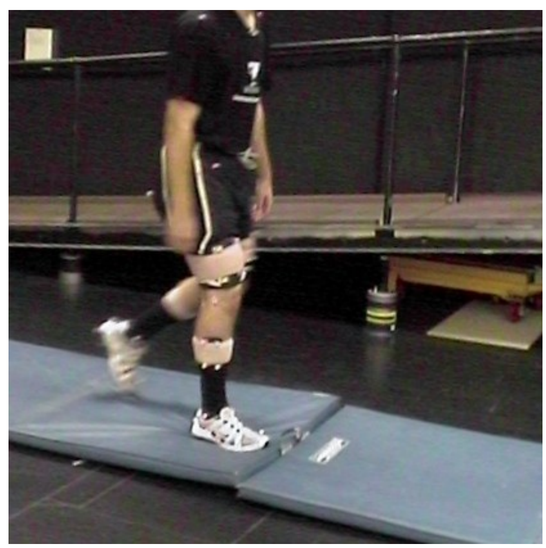

Figure 10: Person walking on uneven ground (ramp surface in background).

Marker and GRF data were processed with the Vicon Nexus software. The Nexus software was used to fill marker gaps and employ a Woltring filter (MSE=10) on the marker data. The data were then exported to Visual3D for calculation of 3D joint and torso angles, velocities, accelerations, moments, and powers. Stride parameters were extracted using Nexus.

3.4 Data Analysis

Test variables were extracted from each trial. Kinetic data were only obtained from stance phase for the level ground walking trials and the test variable locations were based on the events defined by Winter et al. [8, 9, 57]. The kinematic events were recorded for all trials. Values were averaged over the five trials for each task/condition.

The averaged test variables were compared between WOP and WP conditions for each walking task. Outliers were removed for each subject using Tukey's hinges [66], with a value of 3 times the interquartile difference used to ensure that only extreme outliers were removed. By removing outliers for each subject's values, an accurate representation of each subject's gait pattern was reported. Of the 27904 measures in this research (all strides for each test variable), 334 outliers were removed. After the assumption of normality was proved correct using descriptive statistics, paired dependent t-tests with a Bonferroni correction ($p=0.05$) were performed on the subject average for each test variable. Each limb was deemed to be a separate family, as well as the pelvis and trunk data. These family groups had n values of 20 (for each limb) and 18 (for the pelvis and trunk combined). The test variables were also compared to able-bodied data from the literature [9, 67, 68, 69, 70]. Outliers were found for the PEQ responses to determine which participant's scores were abnormal. Pearson correlations were performed to test for relationships between significant and notable test variables and the ambulation and "residual limb health" PEQ subscales. These two subscales were chosen because they were directly relevant to gait changes. In the thesis, only moderate or higher strength results were reported for the Pearson correlations. A moderate strength Pearson correlation coefficient is between 0.40 and 0.69. A high strength correlation coefficient is between 0.70 and 0.89, and a very high strength correlation is between 0.90 and 1.00.

Chapter 4. Results

This chapter presents the results comparing the WP and WOP conditions. Each surface has temporal-spatial and kinematic results but only level ground has kinetic results, due to the need for a force plate. The PEQ scores are also reported. Significant differences were defined as a p-value below the Bonferroni correction value. Notable differences were defined as paired t-test p-values below 0.01. Since this is an exploratory study, notable outcomes are of interest for planning future research. Effect sizes were reported for significant findings.

4.1 Subjects

The participants were all male traumatic, unilateral transtibial amputees with a K-level of 4 and an age range of 21 to 47 years. There were five left and five right side amputations.

Table 3: Description of the ten participants.

Participant Number	Height (m)	Mass (kg)	Age (years)	Years Since Amputation	Prosthetic Foot	Amputation Side
1	1.80	86.17	31	2	flex foot	Right
2	1.80	96.98	34	4.5	c-walk	Right
3	1.75	48.74	43	14	flex foot	Right
5	1.91	119.41	34	1.5	flexfoot	Left
6	1.70	85.66	28	17	ceterus	Left
4	1.73	95.04	21	4	flex foot	Left
7	1.68	81.07	43	5.5	flex foot	Left
9	1.65	74.84	43	4	flex foot	Right
8	1.75	92.53	35	2	flex foot	Left
10	1.78	99.79	47	2.5	flex foot	Right

Participant three had a prosthetic foot that had degraded and was worn to the point that duct tape was required to hold it together. The socket was no longer properly fitted due to recent weight loss attributed to current lifestyle choices. The participant did not want to change his prosthesis.

4.2 Temporal-spatial

Statistically, the limbs were treated as separate families due to the known differences of behaviour in prosthetic and intact limbs. With the overall parameters added to each family, the Bonferroni correction value was 0.003571. ”Stature per second” is the stride rate normalized by an individual’s height. Three parameters have similar names: stride length, intact limb stride length, and prosthetic limb stride length. Intact limb stride length is the stride length between intact limb foot contacts. Prosthetic limb stride length is the stride length between prosthetic limb foot contacts. Stride length (overall) is the average of the two limbs stride lengths.

4.2.1 Level Ground

For the level ground surface, no significant changes were found between WP and WOP conditions for the temporal-spatial variables. In fact, all but two of the variables (step width and double limb support time) differed by less than four percent, between WP and WOP. Means and standard deviations for the ten participants are shown in Table 4: Temporal-spatial parameters for ten participants on level ground. Standard deviations are in brackets. Significant findings are in bold.

4.2.1.1 Overall

There were no overall significant findings on the level ground surface.

4.2.1.2 Intact

There were no intact limb significant results on level ground.

4.2.1.3 Prosthetic

No significant findings occurred at the prosthetic limb on level ground.

Table 4: Temporal-spatial parameters for ten participants on level ground. Standard deviations are in brackets. Significant findings are in bold.

Temporal-spatial Parameter	WP	WOP
Cycle time (s)	1.15 (0.08)	1.14 (0.07)
Speed (m/s)	1.24 (0.08)	1.29 (0.10)
Statures per second	0.69 (0.04)	0.71 (0.05)
Stride length (m)	1.42 (0.09)	1.46 (0.10)
Stride width (m)	0.16 (0.03)	0.17 (0.03)
Double limb support time (s)	0.25 (0.04)	0.22 (0.03)
Intact limb cycle time (s)	1.16 (0.09)	1.14 (0.07)
Intact limb stance time (s)	0.72 (0.06)	0.70 (0.05)
Intact limb step length (m)	0.69 (0.05)	0.72 (0.06)
Intact limb step time (s)	0.56 (0.04)	0.55 (0.04)
Intact limb steps per minute	108.55 (8.22)	108.75 (7.27)
Intact limb stride length (m)	1.39 (0.10)	1.44 (0.11)
Intact limb strides per minute	52.25 (4.00)	52.68 (3.12)
Intact limb swing time (s)	0.43 (0.03)	0.44 (0.02)
Prosthetic limb cycle time (s)	1.15 (0.08)	1.14 (0.06)
Prosthetic limb stance time (s)	0.68 (0.05)	0.66 (0.05)
Prosthetic limb step length (m)	0.72 (0.05)	0.74 (0.05)
Prosthetic limb step time (s)	0.59 (0.05)	0.58 (0.03)
Prosthetic limb steps per minute	101.76 (7.93)	103.37 (5.73)
Prosthetic limb stride length (m)	1.45 (0.10)	1.48 (0.10)
Prosthetic limb strides per minute	52.30 (3.63)	53.00 (2.86)
Prosthetic limb swing time (s)	0.47 (0.04)	0.47 (0.03)

4.2.2 Uneven Ground

Four significant changes were found for uneven ground, when comparing the WP and WOP trials (Table 5). No significant changes were found for the prosthetic limb. The variables that did not significantly change were all within a 4.0% difference, between the WP and WOP conditions (except for double limb support time that had a 9.4% difference).

Table 5: Temporal-spatial parameters for ten participants on uneven ground. Standard deviations are in brackets. Significant findings are in bold.

Temporal-spatial Parameters	WP	WOP
Cycle time (s)	1.19 (0.11)	1.21 (0.08)
Speed (m/s)	1.25 (0.10)	1.28 (0.10)
Statures per second	0.69 (0.07)	0.71 (0.05)
Stride length (m)	**1.47 (0.17)**	**1.55 (0.13)**
Stride width (m)	0.13 (0.03)	0.14 (0.03)
Double limb support time (s)	0.20 (0.05)	0.18 (0.04)
Intact limb cycle time (s)	1.19 (0.10)	1.21 (0.08)
Intact limb stance time (s)	0.71 (0.07)	0.71 (0.06)
Intact limb step length (m)	**0.71 (0.08)**	**0.76 (0.07)**
Intact limb step time (s)	0.58 (0.05)	0.59 (0.04)
Intact limb steps per minute	104.35 (9.22)	102.40 (7.45)
Intact limb stride length (m)	**1.42 (0.17)**	**1.52 (0.14)**
Intact limb strides per minute	50.69 (4.53)	49.90 (3.50)
Intact limb swing time (s)	**0.48 (0.04)**	**0.51 (0.04)**
Prosthetic limb cycle time (s)	1.19 (0.11)	1.21 (0.08)
Prosthetic limb stance time (s)	0.68 (0.06)	0.68 (0.06)
Prosthetic limb step length (m)	0.76 (0.09)	0.79 (0.07)
Prosthetic limb step time (s)	0.61 (0.06)	0.62 (0.04)
Prosthetic limb steps per minute	98.69 (9.46)	97.07 (6.82)
Prosthetic limb stride length (m)	1.52 (0.18)	1.58 (0.14)
Prosthetic limb strides per minute	50.81 (4.61)	49.78 (3.55)
Prosthetic limb swing time (s)	0.51 (0.05)	0.53 (0.04)

4.2.2.1 Overall

Overall stride length significantly decreased with the addition of a weighted pack (M=1.47 m, SD=0.17 m), when compared to the unweighted condition (M=1.55 m, SD=0.13 m), $t(9)=-4.63$, $p<0.003571$, d=1.46.

4.2.2.2 Intact

Intact limb step length for the WP condition (M=0.71 m, SD=0.08 m) was significantly less than the WOP condition (M=0.76 m, SD=0.07 m), $t(9)=-4.88$, $p<0.003571$, d=1.55. Intact limb stride length for WP (M=0.48 m, SD=0.04 m) was significantly less than WOP (*M*=0.51 m, *SD*=0.04 m), *t*(9)=-4.88, p<0.003571, *d*=1.55. Intact limb swing time for WP (*M*=1.42 s, *SD*=0.17 s) was significantly less than WOP (*M*=1.52 s, *SD*=0.14 s), *t*(9)=-5.52, p<0.003571, *d*=1.75.

4.2.2.3 Prosthetic

No significant differences were found for the prosthetic limb on uneven ground.

4.2.3 Ramp Up

The most temporal-spatial gait changes out of the four surfaces were found for the ramp up condition. For the twenty-two values analyzed for temporal-spatial characteristics, nine had either significant or notable changes. More changes occurred on the intact limb compared to the prosthetic limb. On the intact limb, findings that were not significant or notable had less than four percent difference between the WP and WOP conditions. The prosthetic limb differences were less than five percent. The significant findings are in bold text in Table 6.

4.2.3.1 Overall

Walking speed for WP (*M*=1.17 m/s, *SD*=0.12 m/s) was significantly less than WOP (*M*=1.28 m/s, *SD*=0.12 m/s), *t*(9)=-8.69, p<0.003571, *d*=2.75. Statures per second for WP (*M*=0.65, *SD*=0.07) was significantly less than WOP (*M*=0.71, *SD*=0.07), *t*(9)=-8.63, p<0.003571, *d*=2.73. Stride length was significantly less when comparing WP (*M*=1.41 m, *SD*=0.11 m) and WOP (*M*=1.52 m, *SD*=0.10 m), *t*(9)=-7.04, p<0.003571, *d*=2.23. Double limb support time was significantly greater for WP (*M*=0.27 s, *SD*=0.05 s) than WOP (*M*=0.22 s, *SD*=0.04 s), *t*(9)=5.06, p<0.003571, *d*=1.60.

Table 6: Temporal-spatial parameters for ten participants on ramp up. Standard deviations are in brackets. Significant findings are in bold.

Temporal-spatial Parameters	WP	WOP
Cycle time (s)	1.22 (0.14)	1.19 (0.11)
Speed (m/s)	**1.17 (0.12)**	**1.28 (0.12)**
Statures per second	**0.65 (0.07)**	**0.71 (0.07)**
Stride length (m)	**1.41 (0.11)**	**1.52 (0.10)**
Stride width (m)	0.16 (0.03)	0.14 (0.02)
Double limb support time (s)	**0.27 (0.05)**	**0.22 (0.04)**
Intact limb cycle time (s)	1.22 (0.14)	1.19 (0.11)
Intact limb stance time (s)	0.76 (0.10)	0.72 (0.07)
Intact limb step length (m)	**0.67 (0.07)**	**0.73 (0.05)**
Intact limb step time (s)	0.59 (0.07)	0.58 (0.05)
Intact limb steps per minute	103.01 (12.76)	104.13 (9.35)
Intact limb stride length (m)	**1.34 (0.15)**	**1.46 (0.11)**
Intact limb strides per minute	49.91 (5.71)	50.68 (4.68)
Intact limb swing time (s)	0.46 (0.05)	0.48 (0.04)
Prosthetic limb cycle time (s)	1.21 (0.15)	1.19 (0.11)
Prosthetic limb stance time (s)	0.73 (0.10)	0.70 (0.08)
Prosthetic limb step length (m)	**0.73 (0.05)**	**0.79 (0.06)**
Prosthetic limb step time (s)	0.62 (0.07)	0.61 (0.06)
Prosthetic limb steps per minute	97.39 (10.77)	98.60 (9.61)
Prosthetic limb stride length (m)	**1.47 (0.10)**	**1.58 (0.13)**
Prosthetic limb strides per minute	50.23 (6.07)	50.65 (4.53)
Prosthetic limb swing time (s)	0.49 (0.05)	0.50 (0.04)

4.2.3.2 Intact

Intact limb step length was significantly less when comparing the WP condition (*M*=0.67 m, *SD*=0.07 m) to the WOP condition (*M*=0.73 m, *SD*=0.05 m), $t(9)=-4.64$, $p<0.003571$, $d=1.47$. Intact limb stride length for WP (*M*=1.34 m, *SD*=0.15 m) was significantly less than WOP (*M*=1.46 m, *SD*=0.11 m), $t(9)=-4.64$, $p<0.003571$, $d=1.47$.

Intact limb stance time was notably more for the WP condition. WP had a mean of 0.76 (SD= 0.10) seconds while WOP averaged 0.72 (SD= 0.073) seconds.

4.2.3.3 Prosthetic

Prosthetic limb step length was significantly less when comparing WP (*M*=0.73 m, *SD*=0.05 m) and WOP (*M*=0.79 m, *SD*=0.06 m), *t*(9)= -7.21, p<0.003571, *d*=2.28. Prosthetic limb stride length during the WP trials (*M*=1.47 m, *SD*=0.10 m) was significantly less than the WOP trials (*M*=1.58 m, *SD*=0.13 m), *t*(9)= -7.21, p<0.003571, *d*=2.28.

4.2.4 Ramp Down

Ramp down was the surface with the most significant or notable differences at the prosthetic limb, and the only surface to have more differences for the prosthetic limb than the intact limb. However, only one of the three changes seen on the prosthetic limb was significant (Table 7). Less than 3.0% difference between the two experimental conditions was found for the intact limb and all prosthetic limb temporal-spatial measures except swing time.

4.2.4.1 Overall

Double limb support time for the WP condition (*M*=0.23 s, *SD*=0.04 s) was significantly greater than the WOP condition (*M*=0.18 s, *SD*=0.04 s), *t*(9)=6.00, p<0.003571, *d*=1.90.

4.2.4.2 Intact

Intact limb stance time during the WP condition (*M*=0.70 s, *SD*=0.07 s) was significantly more than the WOP condition (*M*=0.66 s, *SD*=0.06 s), *t*(9)= 4.41, p<0.003571, *d*=1.39.

4.2.4.3 Prosthetic

Prosthetic limb stance time was significantly more when comparing WP (*M*=0.67 s, *SD*=0.08 s) and WOP (*M*=0.62 s, *SD*=0.06 s), $t(9)$= 4.25, p<0.003571, *d*=1.34. Prosthetic step and stride length were both notably less with the addition of a weighted pack. Step length had a mean of 0.68 m (SD= 0.08 m) for the WP condition and a mean of 0.70 m (SD= 0.09 m) for the WOP condition. Stride length had a mean of 1.35 m (SD= 0.15 m) with a pack and 1.41 m (SD=0.18 m) without a pack.

Table 7: Temporal-spatial parameters for ten participants on ramp down. Standard deviations are in brackets. Significant findings are in bold.

Temporal-spatial Parameters	WP	WOP
Cycle time (s)	1.14 (0.11)	1.11 (0.09)
Speed (m/s)	1.19 (0.14)	1.25 (0.16)
Statures per second	0.68 (0.09)	0.72 (0.10)
Stride length (m)	1.34 (0.12)	1.34 (0.20)
Stride width (m)	0.15 (0.03)	0.15 (0.03)
Double limb support time (s)	**0.23 (0.04)**	**0.18 (0.04)**
Intact limb cycle time (s)	1.14 (0.11)	1.11 (0.09)
Intact limb stance time (s)	**0.70 (0.07)**	**0.66 (0.06)**
Intact limb step length (m)	0.67 (0.06)	0.68 (0.06)
Intact limb step time (s)	0.56 (0.06)	0.55 (0.05)
Intact limb steps per minute	108.49 (11.40)	110.45 (9.73)
Intact limb stride length (m)	1.33 (0.11)	1.35 (0.13)
Intact limb strides per minute	53.34 (5.22)	54.49 (4.47)
Intact limb swing time (s)	0.44 (0.04)	0.45 (0.04)
Prosthetic limb cycle time (s)	1.14 (0.11)	1.11 (0.09)
Prosthetic limb stance time (s)	**0.67 (0.08)**	**0.62 (0.06)**
Prosthetic limb step length (m)	0.68 (0.08)	0.70 (0.09)
Prosthetic limb step time (s)	0.58 (0.05)	0.56 (0.04)
Prosthetic limb steps per minute	105.07 (9.33)	107.70 (7.97)
Prosthetic limb stride length (m)	1.35 (0.15)	1.41 (0.18)
Prosthetic limb strides per minute	53.32 (5.27)	53.47 (4.53)
Prosthetic limb swing time (s)	0.42 (0.14)	0.49 (0.04)

4.3 Kinematics

Tables with the means for each limb, pelvis, and the trunk are included for each surface, with the significant findings after Bonferroni correction in bold. The Bonferroni correction for the pelvis and trunk values was 0.004167. Each limb was determined to be a statistically separate family because of the known different behaviours between prosthetic and intact limbs. The Bonferroni correction for the limbs was 0.0025. Appendix E provides a key to the abbreviations in Tables 8-15. Figure 11 shows the approximate locations for the test variable labels for the median participant.

4.3.1 Level Ground

Level ground incurred the fewest significant changes to the kinematic test variables. The same number of changes occurred on each limb, with more significant changes on the prosthetic side. However the two significant changes that occurred on the prosthetic side occurred at the ankle and were most likely the consequence of prosthetic foot-ankle deformation. Level ground also incurred the most changes to the pelvis.

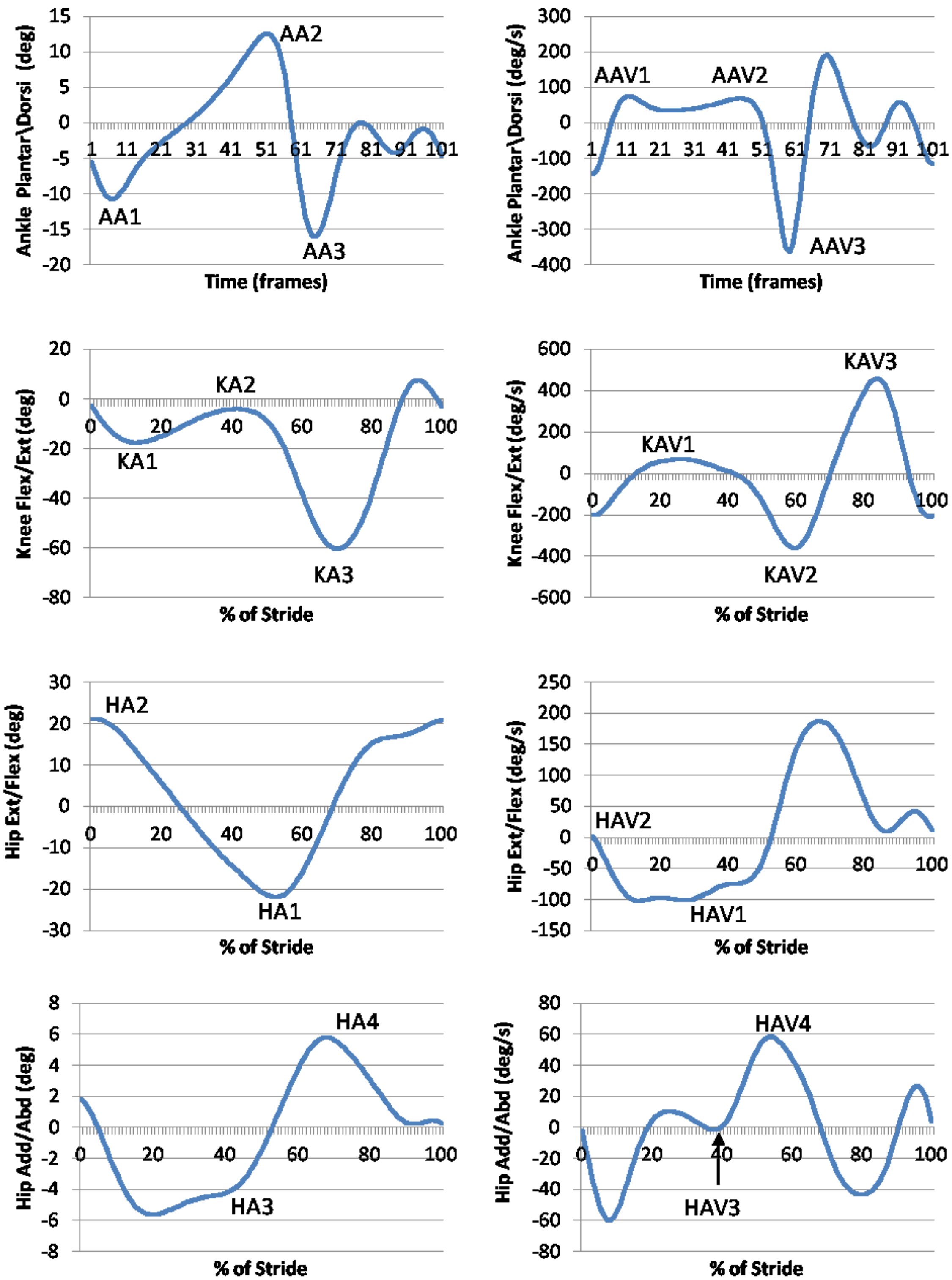

Figure 11: Approximate location of text variables on kinematic curves for the median participant.

4.3.1.1 Pelvis and Trunk

The range of pelvis axial rotation was significantly less for WP (*M*=7.65°, *SD*=4.24°) than WOP (*M*=11.84°, *SD*=5.50°), *t*(9)=-4.68, $p<0.004167$, *d*=1.48. The absolute maximum trunk axial rotation angular velocity was also significantly less for the WP condition (*M*=39.23 deg/s, *SD*=16.35 deg/s) when compared to the WOP condition (*M*=63.58 deg/s, *SD*=16.49 deg/s), *t*(9)=-5.67, $p<0.004167$, *d*=1.79.

Maximum pelvic obliquity and pelvic axial rotation angular velocity were notably less under the WP condition. The WP absolute maximum pelvic obliquity angular velocity had a mean of 21.78 deg/s (SD= 6.54 deg/s) while WOP had a mean of 27.23 deg/s (SD= 10.30 deg/s). Absolute maximum pelvis angular velocity displayed a mean of 29.16 deg/s (SD= 12.58 deg/s) for WP and a mean of 43.17 deg/s (SD= 13.80 deg/s) for WOP, a 39.0% difference (Table 8).

4.3.1.2 Intact Limb

As shown in Table 9, knee angular velocity during midstance was significantly greater for the WP condition (*M*=99.06 deg/s, *SD*=26.43 deg/s) than the WOP condition (*M*=73.18 deg/s, *SD*=23.46 deg/s), *t*(9)=4.41, $p<0.0025$, *d*=1.40.

WP ankle plantarflexion at weight acceptance had a mean of -6.85° (SD= 4.75°) that was notably less than the WOP condition, which had a mean of -9.17° (SD= 4.52°).

Table 8: Test variable means for the pelvis and trunk on level ground. Standard deviations are in brackets. Significant findings are in bold. Abbreviation definitions are in Appendix E.

	WP	WOP
PR1	7.54 (3.41)	5.42 (1.47)
PR2	5.97 (1.92)	6.27 (2.65)
PR3	**7.65 (4.24)**	**11.84 (5.50)**
TR1	7.16 (3.75)	5.22 (4.38)
TR2	8.14 (3.48)	4.35 (8.55)
TR3	10.86 (3.55)	15.75 (15.75)
PAV1	28.90 (11.73)	24.98 (8.74)
PAV2	21.78 (6.54)	27.23 (10.30)
PAV3	29.16 (12.58)	43.17 (13.80)
TAV1	33.19 (13.64)	36.57 (9.07)
TAV2	38.57 (11.88)	46.38 (19.71)
TAV3	**39.23 (16.35)**	**63.58 (16.49)**

Knee angle at weight acceptance was notably greater with the addition of a backpack, mean of -18.71° (SD= 9.17°), when compared to the WOP condition with a mean of -14.07° (SD= 7.12°). The WP knee angle during swing (KA3) which had a mean of -56.46° (SD= 11.89°), was notably less than the WOP mean of -58.63° (SD= 11.26°). Oddly, knee angle before push-off (KA2) did not show either a notable or significant change, even though the percent difference was 164.0% when comparing the two conditions.

Weight acceptance hip flexion increased to a mean of 32.44° (SD= 11.53°) while wearing a weighted backpack when compared to a mean of 24.89° (SD= 10.74°) when WOP.

4.3.1.3 Prosthetic Limb

Ankle dorsiflexion before push-off was significantly greater for the WP condition (M=13.77°, SD=4.43°) than the WOP condition (M=10.92°, SD=4.62°), $t(9)=5.05$, $p<0.0025$, $d=1.60$. Angular velocity for ankle dorsiflexion before push-off was also significantly greater for WP (*M*=69.50 deg/s, *SD*=22.45 deg/s) over WOP (*M*=61.68 deg/s, *SD*=22.99 deg/s), $t(9)=7.50$, $p<0.0025$, $d=2.37$ (Table 9).

Plantarflexion angular velocity at push-off was notably greater for WP, mean of -139.70 deg/s (SD= 36.19 deg/s), than the WP condition, mean of -125.24 deg/s (SD= 36.42 deg/s).

Table 9: Test variable means for the limbs on level ground. Standard deviations are provided in brackets. Significant findings are in bold. Abbreviation definitions are in Appendix E.

	Intact		Prosthetic	
	WP	WOP	WP	WOP
AA1	-6.85 (4.75)	-9.17 (4.52)	-7.24 (5.18)	-7.91 (5.25)
AA2	10.27 (5.56)	10.69 (5.77)	**13.77 (4.43)**	**10.92 (4.62)**
AA3	-19.41 (8.48)	-17.24 (8.84)	-0.68 (4.84)	-1.57 (4.71)
AAV1	81.71 (25.23)	78.54 (21.83)	58.27 (22.09)	52.81 (16.61)
AAV2	47.05 (13.21)	51.63 (14.90)	**69.50 (22.45)**	**61.68 (22.99)**
AAV3	-311.83 (55.45)	-299.11 (56.52)	-139.70 (36.19)	-125.24 (36.42)
KA1	-18.71 (9.17)	-14.07 (7.12)	-6.25 (7.71)	-3.78 (6.56)
KA2	2.45 (6.58)	0.24 (6.05)	4.96 (6.35)	5.06 (6.35)
KA3	-56.46 (11.89)	-58.63 (11.26)	-61.59 (8.23)	-60.39 (7.51)
KAV1	**99.06 (26.43)**	**73.18 (23.46)**	66.95 (37.14)	53.81 (26.36)
KAV2	-336.43 (51.72)	-330.44 (42.60)	-367.41 (41.32)	-354.94 (52.20)
KAV3	363.11 (70.67)	396.79 (69.66)	363.90 (49.53)	370.92 (53.14)
HA1	-13.35 (11.28)	-17.07 (10.16)	-14.76 (9.66)	-18.38 (8.62)
HA2	32.44 (11.53)	24.89 (10.74)	35.23 (11.27)	25.72 (10.45)
HA3	8.45 (4.84)	6.54 (3.94)	4.18 (4.91)	2.93 (4.50)
HA4	-0.99 (4.76)	-2.10 (4.35)	-5.95 (3.35)	-7.01 (4.69)
HAV1	-101.55 (23.00)	-102.05 (17.16)	-128.65 (26.52)	-113.25 (18.79)
HAV2	172.16 (31.51)	161.94 (31.48)	197.81 (21.11)	176.74 (27.34)
HAV3	45.33 (15.92)	48.53 (13.07)	45.93 (9.62)	50.65 (12.28)
HAV4	-47.77 (10.42)	-53.68 (9.30)	-45.59 (15.57)	-54.22 (19.56)

Maximum hip flexion angle at weight acceptance was also notably greater while the participant wore the weighted backpack. The WP trials resulted in a mean of 35.23° (SD= 11.27°) compared to a mean of 25.72° (SD= 10.45°) for the WOP trials. The greater hip flexion angle led to a greater hip flexion angular velocity at weight acceptance, when comparing WP (M=197.81 deg/s, SD= 21.11 deg/s) and WOP (M=-176.74 deg/s, SD= 27.34 deg/s).

4.3.2 Uneven Ground

Uneven ground had the most kinematic changes, and the second most significant changes, with the addition of the weighted backpack. This surface also had the most changes for the intact limb, with the majority of changes occurring at the knee and hip.

4.3.2.1 Pelvis and Trunk

The pelvis axial rotation range was significantly less for the WP condition (*M*=8.27°, *SD*=2.76°) than the WOP condition (*M*=14.21°, *SD*=5.25°), *t*(9)=-4.08, p<0.004167, *d*=1.29. The absolute maximum trunk axial rotation angular velocity was significantly less for WP (*M*=45.53 deg/s, *SD*=17.02 deg/s) than WOP (*M*=71.08 deg/s, *SD*=10.25 deg/s), *t*(9)=-4.29, p<0.004167, *d*=1.36 (Table 10).

4.3.2.2 Intact Limb

Ankle plantarflexion at weight acceptance was significantly less for WP (*M*=-0.52°, *SD*=4.55°) than WOP (*M*=-2.94°, *SD*=4.32°), *t*(9)=5.11, p<0.0025, *d*=1.69. Ankle plantarflexion displayed the biggest percent difference (140.0%) between WP and WOP out of all of test variables for uneven ground. Knee angle during weight acceptance was significantly more flexed for WP (*M*=-19.82°, *SD*=7.91°) than WOP (*M*=-13.97°, *SD*=6.53°) on uneven ground, *t*(9)=-6.03, p<0.0025, *d*=1.91. Knee angular velocity during midstance was significantly greater for WP (*M*=118.21 deg/s, *SD*=27.30 deg/s) than WOP (*M*=84.36 deg/s, *SD*=24.13 deg/s), *t*(9)=5.40, p<0.0025, *d*=1.71. Maximum hip flexion was significantly greater for WP (*M*=42.89°, *SD*=10.77°) than WOP (*M*=32.11°, *SD*=10.71°), *t*(9)=8.05, p<0.0025, *d*=2.55. Table 11 shows the means for the intact limb, with the significant findings in bold.

Dorsiflexion angular velocity before push-off was notably more for WP, with a mean of 63.98 deg/s (SD= 21.47 deg/s), when compared to WOP, with a mean of 57.60 deg/s (SD= 23.60 deg/s).

Table 10: Test variable means for the pelvis and trunk on uneven ground. Standard deviations are provided in brackets. Significant findings are in bold. Abbreviation definitions are in Appendix E.

	WP	WOP
PR1	7.94 (4.40)	5.15 (1.30)
PR2	8.52 (2.19)	8.24 (1.88)
PR3	**8.27 (2.76)**	**14.21 (5.25)**
TR1	7.24 (6.94)	6.30 (5.79)
TR2	8.59 (6.66)	9.04 (7.06)
TR3	8.62 (9.09)	15.16 (15.39)
PAV1	32.11 (21.78)	21.31 (6.19)
PAV2	30.43 (7.93)	31.67 (8.87)
PAV3	33.33 (13.96)	47.27 (12.18)
TAV1	45.66 (20.07)	43.08 (9.38)
TAV2	49.33 (15.78)	50.77 (16.88)
TAV3	**45.53 (17.02)**	**71.08 (10.25)**

Knee angular velocity during swing was notably more flexed and notably less extended for the WP condition, as compared to the WOP condition. WP knee swing flexion angular velocity had a mean of -420.24 deg/s (SD=67.58 deg/s) and WOP swing flexion had a mean of -389.74 deg/s (SD= 51.29 deg/s). WP swing extension angular velocity had a mean of 392.19 deg/s (SD= 69.31 deg/s) and WOP swing extension angular velocity had a mean 442.31 deg/s (SD= 78.11 deg/s).

Max extension hip angle at push-off was notably less for WP, with a mean of -13.60° (SD= 8.35°), than WOP, with a mean of -19.21° (SD= 9.76°). Maximum hip flexion angular velocity at weight acceptance was notably greater for WP, mean of 235.54 deg/s (SD= 28.96 deg/s), than WOP, mean of 211.60 deg/s (SD= 25.00 deg/s).

4.3.2.3 Prosthetic Limb

Ankle dorsiflexion before push-off, on uneven ground, was significantly greater for WP (*M*=13.49°, *SD*=4.59°) than WOP (*M*=11.88°, *SD*=4.34°), $t(9)=11.04$, $p<0.0025$, $d=3.49$. During weight acceptance, the knee was significantly more flexed for the WP condition (*M*=-5.94°, *SD*=7.17°) when compared to the WOP condition (*M*=-2.13°, *SD*=5.08°), $t(9)=-4.29$, $p<0.0025$, $d=1.36$. Knee flexion angular velocity during swing was significantly greater for WP (*M*=-435.65 deg/s, *SD*=54.34 deg/s) than WOP (*M*=-413.22 deg/s, *SD*=49.52 deg/s), $t(9)=-4.95$, $p<0.0025$, $d=1.57$. The max hip flexion angle was significantly greater for WP (*M*=44.40°, *SD*=8.90°) than WOP (*M*=33.77°, *SD*=7.85°), $t(9)=6.12$, $p<0.0025$, $d=1.93$.

4.3.3 Ramp Up

The ramp up surface resulted in the most significant changes in kinematic test variables. This surface also produced one of the largest percent differences at 200 percent for knee extension during push-off on the intact limb. Ramp up was the only surface to show no significant or notable changes at the pelvis. In total, only two comparisons were not significant, the highest percentage of significant changes on a surface.

4.3.3.1 Pelvis and Trunk

As shown in Table 12, trunk axial rotation range was significantly less for the WP condition (*M*=11.73°, *SD*=4.07°) when compared to the WOP condition (*M*=23.09°, *SD*=5.58°), $t(9)= -6.85$, $p<0.004167$, $d=2.17$. Maximum absolute trunk axial rotation angular velocity was significantly less for WP (*M*=41.68 deg/s, *SD*=10.76 deg/s) than WOP (*M*=70.41 deg/s, *SD*=14.57 deg/s), *t*(9)=-6.77, p<0.004167, *d*=2.14.

Table 11: Test variable means for the limbs on uneven ground. Standard deviations are in brackets. Significant findings are in bold. Abbreviation definitions are in Appendix E.

	Intact		Prosthetic	
	WP	WOP	WP	WOP
AA1	**-0.52 (4.55)**	**-2.94 (4.32)**	-5.25 (4.98)	-5.44 (4.97)
AA2	9.58 (5.65)	10.61 (5.59)	**13.49 (4.59)**	**11.88 (4.34)**
AA3	-21.01 (9.76)	-18.72 (10.11)	-0.61 (4.46)	-0.66 (4.49)
AAV1	62.08 (14.65)	63.10 (15.30)	47.02 (18.15)	40.93 (12.24)
AAV2	29.60 (14.07)	38.23 (11.13)	63.98 (21.47)	57.60 (23.60)
AAV3	-289.36 (57.41)	-293.50 (52.24)	-146.99 (41.68)	-133.85 (42.06)
KA1	**-19.82 (7.91)**	**-13.97 (6.53)**	**-5.94 (7.17)**	**-2.13 (5.08)**
KA2	3.03 (7.15)	2.06 (6.47)	5.87 (7.20)	6.00 (6.09)
KA3	-70.66 (9.54)	-71.61 (10.36)	-76.63 (7.38)	-75.91 (7.21)
KAV1	**118.21 (27.30)**	**84.36 (24.13)**	78.49 (37.23)	56.07 (27.19)
KAV2	-420.24 (67.58)	-389.74 (51.29)	**-435.65 (54.34)**	**-413.22 (49.52)**
KAV3	392.19 (69.31)	442.31 (78.11)	414.31 (56.81)	420.28 (48.58)
HA1	-13.60 (8.35)	-19.21 (9.76)	-12.81 (10.22)	-18.61 (8.84)
HA2	**42.89 (10.77)**	**32.11 (10.71)**	**44.40 (8.90)**	**33.77 (7.85)**
HA3	7.64 (4.91)	5.79 (4.12)	4.40 (4.50)	2.55 (3.42)
HA4	-2.59 (4.33)	-3.30 (4.42)	-5.63 (4.02)	-6.63 (2.45)
HAV1	-127.24 (19.05)	-118.21 (17.87)	-135.41 (26.21)	-121.72 (13.69)
HAV2	235.54 (28.96)	211.60 (25.00)	233.31 (31.25)	209.18 (28.21)
HAV3	55.82 (11.97)	57.85 (13.39)	43.03 (13.57)	44.43 (13.05)
HAV4	-58.51 (19.65)	-57.45 (19.33)	-45.83 (9.92)	-49.27 (17.87)

4.3.3.2 Intact Limb

Ankle plantarflexion at weight acceptance was significantly greater for WP (*M*=7.64°, *SD*=4.72°) than WOP (*M*=2.70°, *SD*=4.97°), *t*(9)=7.03, p<0.0025, *d*=2.22. Ankle dorsiflexion before push-off was significantly greater for WP (*M*=16.91°, *SD*=4.55°) than WOP (*M*=13.24°, *SD*=5.47°), *t*(9)=5.82, p<0.0025, *d*=1.84. Before push-off, the knee was significantly more flexed for the WP condition (*M*=-1.56°, *SD*=8.33°) than the WOP condition (*M*=2.82°, *SD*=6.99°), *t*(9)=-4.37, p<0.0025, *d*=1.38. Maximum hip flexion angle was significantly greater for WP (*M*=48.21°, *SD*=9.46°) than WOP (*M*=39.45°, *SD*=10.22°), *t*(9)=6.30, p<0.0025, *d*=1.99.

Table 12: Test variable means for the pelvis and trunk on ramp up. Standard deviations are in brackets. Significant findings are in bold. Abbreviation definitions are in Appendix E.

	WP	WOP
PR1	6.11 (1.75)	4.82 (0.85)
PR2	12.13 (2.84)	10.77 (2.91)
PR3	7.84 (2.03)	9.03 (3.10)
TR1	6.98 (1.69)	5.61 (1.10)
TR2	15.38 (5.30)	16.34 (5.62)
TR3	**11.73 (4.07)**	**23.09 (5.58)**
PAV1	24.79 (7.71)	22.50 (7.43)
PAV2	42.33 (9.74)	42.59 (9.79)
PAV3	33.78 (9.97)	44.00 (10.57)
TAV1	33.19 (12.98)	30.90 (12.96)
TAV2	56.57 (20.16)	63.24 (19.72)
TAV3	**41.68 (10.76)**	**70.41 (14.57)**

Knee angle at weight acceptance was notably greater under the WP condition, a mean of -34.74° (SD= 10.49°), than the WOP condition, a mean of -25.62° (SD=7.64°). The WP mean for swing extension knee angular velocity (*M*=215.55 deg/s, *SD*= 73.56 deg/s) was notably less than the WOP mean of 269.91 deg/s (SD= 69.40 deg/s). The two left columns of Table 13 display the intact limb means, with the significant findings in bold.

4.3.3.3 Prosthetic Limb

Ankle plantarflexion at weight acceptance was significantly less for the WP condition (M=-4.22°, SD=4.61°) than the WOP condition (M=-5.78°, SD=4.62°), $t(9)=4.68$, $p<0.0025$, d=1.48. Ankle dorsiflexion before push-off was significantly greater for WP (M=14.23°, SD=5.03°) than WOP (M=12.31°, SD=4.74°), $t(9)=7.53$, $p<0.0025$, d=2.38. The knee was significantly more flexed during weight acceptance for the WP trials (M=-12.32°, SD=11.35°) when compared to the WOP trials (M=-6.22°, SD=10.21°), $t(9)=-6.26$, $p<0.0025$, d=1.97. Knee extension angular velocity during swing was significantly less for WP (M=283.53 deg/s, SD=42.10 deg/s) than WOP (M=323.66 deg/s, SD=46.61 deg/s), t(9)=-5.57, p<0.0025, d=1.76. WP and WOP maximum hip flexion and extension angles were also significantly different. WP maximum hip flexion (M=-11.21°, SD=7.37°) was significantly less than WOP (M=-17.47°, SD=8.53°), t(9)=4.91, p<0.0025, d=1.55. Weighted maximum hip extension was significantly greater during the WP condition (M=46.05°, SD=9.20°) than the WOP condition (M=37.89°, SD=9.87°) on ramp up, t(9)=-4.42, p<0.0025, d=1.40 (Table 13).

4.3.4 Ramp Down

Ramp down had the fewest kinematic changes between WP and WOP conditions. While the fewest changes were found for the intact limb for any surface, the most changes to the trunk, including the most significant changes, were found for the ramp down surface.

4.3.4.1 Pelvis and Trunk

The means and standard deviations for the pelvis and trunk test variables are presented in Table 14. The trunk axial rotation range was significantly less for the WP condition (*M*=7.32°, *SD*=2.54°) than the WOP condition (*M*=15.33°, *SD*=5.90°), *t*(9)=-5.72, p<0.004167, *d*=1.81. The absolute maximum pelvic rotation angular velocity was significantly less while wearing a weighted backpack (*M*=22.53 deg/s, *SD*=6.59 deg/s) than the WOP condition (*M*=48.44 deg/s, *SD*=23.43 deg/s), *t*(9)=-4.32, p<0.004167, *d*=1.37. The absolute maximum trunk flexion angular velocity was significantly less during the WP trials (*M*=39.62 deg/s, *SD*=10.19 deg/s) when compared to the WOP trials (*M*=58.07 deg/s, *SD*=22.09 deg/s), *t*(9)=-4.05, p<0.004167, *d*=1.28. The absolute maximum trunk axial rotation angular velocity was significantly less for WP (*M*=33.13

deg/s, *SD*=11.60 deg/s) than WOP (*M*=62.95 deg/s, *SD*=28.72 deg/s), $t(9)=-4.13$, $p<0.004167$, $d=1.31$.

Table 13: Test variable means for the limbs on ramp up. Standard deviations are provided in brackets. Significant findings are in bold. Abbreviation definitions are in Appendix E.

	Intact		Prosthetic	
	WP	WOP	WP	WOP
AA1	**7.64 (4.72)**	**2.70 (4.97)**	**-4.22 (4.61)**	**-5.78 (4.62)**
AA2	**16.91 (4.55)**	**13.24 (5.47)**	**14.23 (5.03)**	**12.31 (4.74)**
AA3	-25.49 (8.17)	-23.77 (8.29)	-1.36 (4.68)	-1.25 (4.24)
AAV1	69.24 (24.76)	63.03 (17.51)	59.42 (29.95)	48.44 (18.73)
AAV2	9.93 (22.24)	16.73 (22.05)	60.46 (20.93)	64.47 (22.68)
AAV3	-327.77 (53.75)	-323.36 (53.42)	-139.75 (44.92)	-132.84 (46.96)
KA1	-34.74 (10.49)	-25.62 (7.64)	**-12.32 (11.35)**	**-6.22 (10.21)**
KA2	**-1.56 (8.33)**	**2.82 (6.99)**	7.21 (11.71)	10.31 (6.66)
KA3	-53.88 (12.16)	-52.83 (11.39)	-61.42 (8.79)	-60.77 (7.96)
KAV1	131.25 (19.06)	118.64 (29.89)	113.42 (42.33)	94.81 (57.67)
KAV2	-310.65 (61.06)	-306.47 (65.32)	-355.20 (51.96)	-354.52 (51.88)
KAV3	215.55 (73.56)	269.91 (69.40)	**283.53 (42.10)**	**323.66 (46.61)**
HA1	-9.81 (11.41)	-16.57 (10.84)	**-11.21 (7.37)**	**-17.47 (8.53)**
HA2	**48.21 (9.46)**	**39.45 (10.22)**	**46.05 (9.20)**	**37.89 (9.87)**
HA3	9.84 (4.58)	7.37 (4.57)	6.10 (4.97)	3.95 (4.82)
HA4	-4.06 (5.72)	-3.71 (4.87)	-7.39 (4.59)	-6.81 (3.76)
HAV1	-133.80 (15.62)	-135.37 (17.55)	-133.23 (47.35)	-141.26 (31.40)
HAV2	200.08 (22.14)	191.59 (29.76)	200.88 (64.08)	202.65 (32.11)
HAV3	60.07 (13.45)	58.41 (14.87)	45.30 (23.32)	45.70 (16.03)
HAV4	-50.16 (10.63)	-49.79 (19.12)	-42.61 (19.09)	-50.13 (17.82)

Both trunk abduction/adduction range and maximum angular velocity incurred notable changes with the addition of the weighted backpack. WP trunk abduction/adduction range, with a mean of 6.73° (SD= 2.33°), was notably less than the WOP mean of 10.88° (SD= 4.66°). WP trunk abduction/adduction maximum angular velocity, with a mean of 34.52 deg/s (SD= 12.67 deg/s), was notably less than the WOP condition, with a mean of 55.08 deg/s (SD= 17.04 deg/s).

4.3.4.2 Intact Limb

Knee angle during swing was significantly less flexed for WP (*M*=-63.53°, *SD*=10.86°) than WOP (*M*=-66.53°, *SD*=11.72°), *t*(9)=5.31, p<0.0025, *d*=1.68. The one significant finding for the intact limb is in bold in the two left columns of Table 15.

Table 14: Test variable means for the pelvis and trunk on ramp down. Standard deviations are in brackets. Significant findings are in bold. Abbreviation definitions are in Appendix E.

	WP	WOP
PR1	6.94 (1.12)	7.77 (2.16)
PR2	6.73 (2.17)	7.68 (1.83)
PR3	6.02 (2.40)	12.91 (7.15)
TR1	6.74 (1.24)	9.33 (2.86)
TR2	6.73 (2.33)	10.88 (4.66)
TR3	**7.32 (2.54)**	**15.33 (5.90)**
PAV1	44.30 (12.71)	50.07 (12.71)
PAV2	35.54 (10.33)	43.72 (10.33)
PAV3	**22.53 (6.59)**	**48.44 (6.59)**
TAV1	**39.62 (10.19)**	**58.07 (10.19)**
TAV2	34.52 (12.67)	55.08 (12.67)
TAV3	**33.13 (11.60)**	**62.95 (11.60)**

4.3.4.3 Prosthetic Limb

Ankle plantarflexion at weight acceptance was significantly greater for the WP condition (*M*=-9.92°, *SD*=4.73°) than the WOP condition (*M*=-9.35°, *SD*=4.59°), *t*(9)=-4.42, p<0.0025, *d*=1.40. Ankle dorsiflexion before push-off was significantly greater for WP (*M*=11.61°, *SD*=4.73°) than WOP (*M*=9.71°, *SD*=4.52°), *t*(9)=7.05, p<0.0025, *d*=2.23. Before push-off, the knee was significantly less flexed for the WP condition (*M*=-5.03°, *SD*=6.94°) than the WOP condition (*M*=-9.73°, *SD*=6.30°), *t*(9)=-4.59, p<0.0025, *d*=1.45. The knee flexion angular velocity during swing was significantly greater for WP (*M*=-368.73 deg/s, *SD*=77.85 deg/s) than WOP (*M*=-321.53 deg/s, *SD*=71.42 deg/s), *t*(9)=-4.96, p<0.0025, *d*=1.57. Maximum hip flexion angular velocity was significantly greater for WP (*M*=166.47 deg/s, *SD*=30.54 deg/s) than WOP (*M*=137.78 deg/s, *SD*=32.04 deg/s), $t(9)=5.80$, $p<0.0025$, $d=1.84$.

The knee was more extended at weight acceptance during the WP trials, with a mean of -9.38° (SD= 9.18°), when compared to the WOP mean of -13.74° (SD= 7.01°) (Table 15).

Table 15: Test variable means for the limbs on ramp down. Standard deviations are provided in brackets. Significant findings are in bold. Abbreviation definitions are in Appendix E.

	Intact		Prosthetic	
	WP	WOP	WP	WOP
AA1	-12.61 (4.38)	-11.50 (5.15)	**-9.92 (4.73)**	**-9.35 (4.59)**
AA2	16.84 (5.78)	16.59 (6.19)	**11.61 (4.73)**	**9.71 (4.52)**
AA3	-10.44 (8.23)	-9.85 (9.46)	-2.05 (5.56)	-2.04 (4.84)
AAV1	101.27 (26.00)	99.66 (20.34)	72.71 (31.75)	77.37 (25.17)
AAV2	78.16 (8.17)	84.25 (15.73)	65.83 (25.60)	60.25 (18.21)
AAV3	-313.30 (76.37)	-298.03 (56.39)	-132.79 (55.42)	-117.27 (42.76)
KA1	-19.12 (8.10)	-21.06 (9.01)	-9.38 (9.18)	-13.74 (7.01)
KA2	-14.90 (6.56)	-16.49 (6.93)	**-5.03 (6.94)**	**-9.73 (6.30)**
KA3	**-63.53 (10.86)**	**-66.53 (11.72)**	-66.29 (9.41)	-68.65 (7.95)
KAV1	38.16 (24.84)	40.64 (17.67)	31.08 (39.29)	22.13 (39.14)
KAV2	-296.55 (77.83)	-287.07 (46.89)	**-368.73 (77.85)**	**-321.53 (71.42)**
KAV3	415.42 (84.01)	422.73 (73.77)	373.58 (61.48)	374.39 (54.64)
HA1	-9.08 (10.06)	-13.09 (11.33)	-10.57 (10.12)	-9.81 (12.19)
HA2	24.98 (10.63)	18.47 (11.50)	25.21 (9.21)	19.31 (10.48)
HA3	8.35 (5.34)	7.54 (4.50)	3.93 (5.11)	3.15 (3.88)
HA4	-2.00 (4.76)	-3.12 (4.81)	-5.67 (4.70)	-7.24 (4.37)
HAV1	-93.15 (16.11)	-96.11 (22.25)	**-99.09 (29.30)**	**-93.41 (27.59)**
HAV2	163.53 (24.12)	155.30 (23.47)	166.47 (30.54)	137.78 (32.04)
HAV3	58.09 (21.70)	60.46 (27.74)	47.71 (12.22)	54.12 (19.36)
HAV4	-52.04 (12.51)	-58.69 (18.62)	-54.15 (28.66)	-58.18 (36.01)

4.4 Kinetics

The means for the 16 kinetic test variables are included in Table 16, with the results that are significant after the Bonferroni correction in bold. The Bonferroni correction was determined to be 0.003125. Again each limb was deemed to be a significantly separate family because of the known different behaviours between prosthetic and intact limbs. A key for the kinetic value labels is provided in Table 2: Common descriptions for power bursts created by Winter et al. [8, 57]. and Appendix E.

4.4.1 Level Ground

The level ground surface had changes in kinetic test variables at the prosthetic limb but no significant changes for the intact limb test variables, and only one notable change (Table 16). However, except for a 0.11% difference between the two conditions for maximum hip extension moment, all changes had at least a 9% difference between WP and WOP conditions.

4.4.1.1 Intact Limb

There were no significant results for the intact limb when comparing the two conditions.

The KP2 power burst, that extends the knee during mid-stance, notably increased with the addition of the weighted backpack.

Table 16: Moment and power test variable means for the limbs on level ground. Standard deviations are provided in brackets. Significant results are in bold. Abbreviation definitions are in Appendix E.

	Intact		Prosthetic	
	WP	WOP	WP	WOP
AM1	15.50 (8.35)	18.57 (6.98)	21.09 (10.22)	19.80 (11.50)
AM2	-149.47 (62.43)	-135.80 (35.01)	**-154.79 (41.18)**	**-128.70 (38.08)**
AP1	-26.29 (24.46)	-29.64 (19.63)	-20.50 (13.38)	-20.62 (12.97)
AP2	5.61 (8.39)	7.39 (8.67)	8.78 (9.52)	8.73 (10.51)
AP3	-1.98 (5.87)	-8.38 (9.34)	-6.64 (7.87)	-4.79 (9.34)
AP4	384.85 (242.84)	295.99 (112.64)	222.92 (106.73)	193.70 (112.90)
KM1	93.47 (58.71)	55.08 (20.04)	46.73 (46.92)	32.01 (32.58)
KM2	-26.22 (16.14)	-17.46 (15.84)	-21.03 (20.49)	-25.99 (14.91)
KP1	-115.33 (83.54)	-62.42 (39.76)	-49.48 (60.40)	-40.16 (40.20)
KP2	114.90 (79.10)	36.16 (30.03)	46.63 (60.49)	27.48 (23.25)
KP3	-133.14 (81.26)	-94.47 (39.34)	**-112.76 (85.94)**	**-73.12 (63.85)**
HM1	-47.33 (37.16)	-47.28 (19.85)	-33.51 (25.88)	-32.40 (21.69)
HM2	106.49 (55.17)	96.91 (39.63)	**127.05 (40.27)**	**94.98 (35.24)**
HP1	19.06 (14.10)	25.93 (14.97)	39.10 (45.57)	39.09 (39.08)
HP2	-93.64 (60.30)	-76.24 (37.31)	**-127.33 (48.37)**	**-67.21 (27.96)**
HP3	96.28 (54.99)	82.74 (42.03)	108.34 (53.13)	75.04 (35.92)

4.4.2.1 Prosthetic Limb

The maximum ankle plantarflexion moment was significantly greater for the WP condition (*M*=-154.79 Nm, *SD*=41.18 Nm) when compared to the WOP condition (*M*=-128.70 Nm, *SD*=38.08 Nm), $t(9)=-10.72$, $p<0.003125$, $d=3.39$ (Figure 12).

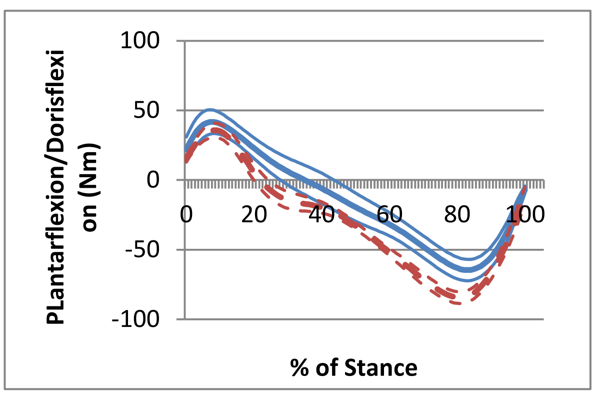

Figure 12: Median subject prosthetic ankle moment curve during stance phase.

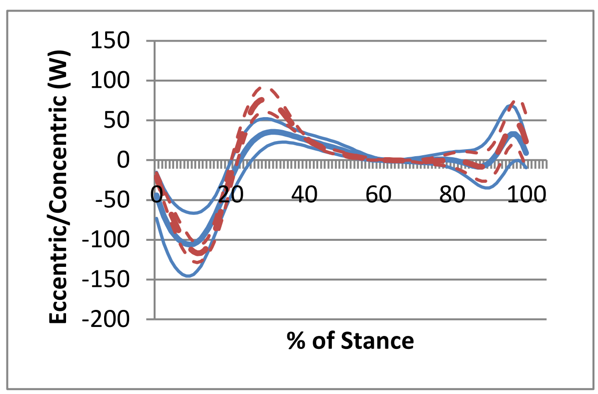

Figure 13: Median subject prosthetic knee power curve during stance phase.

Knee extensor net joint power during push-off, as the knee flexes (KP3), was significantly greater for the WP condition (*M*=-112.76 W, *SD*=85.94 W) than the WOP condition (*M*=-73.12 W, *SD*=63.85 W), *t*(9)=-4.00, p<0.003125, *d*=1.27 (Figure 13). The maximum hip flexion moment was significantly greater for WP (*M*=127.05 Nm, *SD*=40.27 Nm) than WOP (*M*=94.98 Nm, *SD*=35.24 Nm), *t*(9)=5.52, p<0.003125, *d*=1.27 (Figure 14). Hip flexor power, that decelerated the backward rotating thigh when transitioning from stance to toe-off (HP2), was significantly greater for WP (*M*=-127.33 W, *SD*=48.37 W) than WOP (*M*=-67.21 W, *SD*=27.96 W), *t*(9)=-4.57, p<0.003125, *d*=1.45 (Figure 15).

Energy generated by the hip during late stance and early swing, corresponding to the HP3 power burst notably increased when comparing the WP condition to the WOP condition.

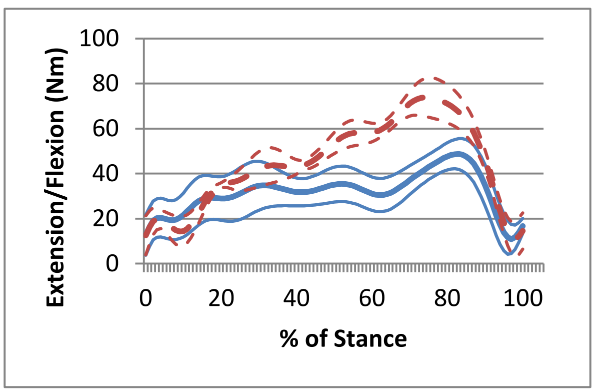

Figure 14: Median subject prosthetic hip moment curve during stance phase.

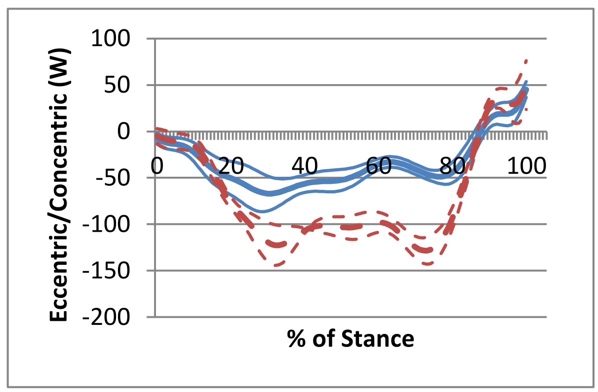

Figure 15: Median subject prosthetic hip power curve during stance phase.

4.5 Prosthesis Evaluation Questionnaire (PEQ)

The scores for each subscale for each participant on the PEQ are shown in Table 17. There were only four outliers in the entire set of results. Participant three was the most different in his responses when compared to the other participants, as displayed by the three outliers for his results. Well-being was the subscale that resulted in the most variability because it contained two outliers.

Table 17: Subscale scores for prosthesis evaluation questionnaire (PEQ) results for ten subjects. Significant outliers are in bold. Standard deviations are in brackets.

PEQ Subscale	Subject Number										
	1	2	3	4	5	6	7	8	9	10	Mean (SD)
Ambulation	68.4	58.5	26.4	82.6	85.4	88.8	91.1	59.0	88.4	68.3	71.69(20.18)
Appearance	55.4	74.8	20.3	86.4	93.4	85.8	77.5	41.4	71.3	92.6	69.89(23.94)
Frustration	20.0	61.0	13.5	96.5	92.0	78.5	97.0	91.0	88.0	51.0	68.85(31.40)
Perceived Response	72.6	73.0	**23.0**	95.8	94.3	81.0	87.0	94.6	96.8	97.0	81.51(22.65)
Residual Limb Health	40.2	42.2	21.3	91.0	92.7	73.7	89.5	51.3	85.8	86.5	67.42(26.22)
Social Burden	65.7	71.0	**21.0**	77.3	94.0	79.0	94.0	92.7	94.3	97.0	78.60(23.10)
Sounds	28.5	24.0	62.5	80.5	89.0	96.0	88.0	48.5	96.5	42.0	65.55(28.12)
Utility	81.4	73.6	32.4	84.9	88.4	95.8	81.6	68.3	86.3	73.6	76.63(17.51)
Well Being	**56.5**	77.5	**45.5**	88.5	93.5	85.5	92.0	81.5	91.0	86.5	79.80(16.13)

Pearson correlations were performed for each of the significant and notable test variables with two gait-related PEQ subscales, ambulation and "perceived residual limb health". These subscales were chosen because they were directly relevant to gait changes. There were no moderate or higher strength correlations reported for the temporal-spatial parameters on any of the four surfaces. Pearson correlation results are located in Appendix J.

4.5.1 Ambulation Subscale

4.5.1.1 Level Ground

Pelvis axial rotation range for WOP was moderately correlated with the ambulation subscale (r= -0.51, p=0.13). For the WP condition, this variable was highly correlated (r= -0.83, p=0.00). A moderate correlation for absolute maximum pelvic axial rotation angular velocity was found with the WOP condition (r= -0.44, p=0.20). For WP, a high correlation occurred (r= -0.71, p=0.02). Trunk axial rotation angular velocity during the WOP trials was negatively correlated with the ambulation subscale at a moderate level (r= -0.63, p=0.05). The WP condition was highly correlated (r= -

0.79, *p*=0.01). Plantarflexion angular velocity on the prosthetic limb during weight acceptance was moderately correlated between the ambulation subscale and WOP condition (r= -0.42, *p*=0.22).

For significant or notable kinetic results, there were no correlations of at least a moderate strength level for the ambulation subscale.

4.5.1.2 Uneven Ground

Uneven ground only had one correlation of at least a moderate strength level. The correlation was negative for the WOP condition and the ambulation subscale for pelvic axial rotation range (r= -0.44, *p*=0.20).

4.5.1.3 Ramp Up

A moderate strength correlation was found for trunk axial rotation range for the WOP condition and the ambulation subscale (r=-0.53, *p*=0.12).

Both the WP condition (r= -0.49, *p*=0.89) and the WOP condition (r= -0.53, *p*=0.12) were moderately correlated with the ambulation subscale on the prosthetic limb. Prosthetic limb maximum hip extension during push-off was moderately correlated in a positive direction for the WP condition and the PEQ subscale (r= 0.43, *p*=0.21).

On the intact limb ankle dorsiflexion before push-off was moderately correlated for the WP condition and the ambulation subscale (r= -0.40, *p*=0.25). A positive moderate strength correlation for the WP condition and the PEQ subscale was found for knee extension during push-off on the intact limb (r= 0.45, *p*=0.19).

4.5.1.4 Ramp Down

No correlations of at least a moderate strength level were found on the ramp down surface for either of the limbs. However there were correlations to the pelvis and trunk.

WP trunk axial rotation range was moderately correlated with the ambulation subscale (r= -0.48, *p*=0.16). WOP condition moderate correlations were found for absolute maximum pelvis axial rotation velocity (r= -0.48, *p*=0.16), trunk flexion velocity (r= -0.42, *p*=0.23), and trunk axial rotation velocity (r= -0.52, *p*=0.13).

4.5.2 Residual Limb Health Subscale

4.5.2.1 Level Ground

The pelvic axial rotation range (WP condition) was moderately correlated with the "residual limb health" subscale (r= -0.64, *p*=0.05). The angular velocity also was negatively correlated at a moderate strength level for the WP condition (r= -0.62, *p*=0.05). Absolute maximum trunk axial rotation velocity was moderately correlated with this PEQ subscale in a negative direction for both the WP condition (r= -0.61, *p*=0.06) and the WOP condition (r= -0.44, *p*=0.21)

A moderate correlation was found between the "residual limb health" subscale and the WP condition on the intact limb for both knee angle during weight acceptance (r= 0.44, *p*=0.21) and knee angle during swing (r= 0.41, *p*=0.24). Intact limb hip flexion angle during weight acceptance was negatively correlated between the "residual limb health" subscale and WP at a moderate strength level (r= -0.46, *p*=0.18).

For the kinetic test variables that were either significant or notable there was only one correlation of a moderate strength level. The WP HP2 power burst was a negative correlation with the "residual limb health" subscale (r= -0.48, p=0.16).

4.5.2.2 Uneven Ground

There were no correlations of at least a moderate strength level on either condition for the uneven ground surface.

4.5.2.3 Ramp Up

A moderate correlation was found for the knee angle during weight acceptance was found for the WP condition (r=0.43, p=0.22) and the WOP condition (r=0.42, p=0.23) when compared to the "residual limb health" PEQ subscale on the prosthetic limb, and for the WP condition on the intact limb (r= 0.43, p=0.22). Intact limb knee angle before push-off was moderately correlated with a positive relationship for both the WP condition (r= 0.56, p=0.09) and the WOP condition (r= 0.45, p=0.19) with the "residual limb health" subscale.

4.5.2.4 Ramp Down

No correlations of at least a moderate strength level were found on the ramp down surface for either of the limbs. However there were correlations to the pelvis and trunk. Moderate strength correlations were found for the WOP condition and the "residual limb health" subscale for absolute maximum trunk flexion velocity (r=-0.44, p=0.20) and absolute maximum trunk axial rotation velocity (r=-0.44, p=0.21).

Chapter 5. Discussion

Carrying a weighted backpack significantly changed amputee gait. Some of these changes were consistent with the literature for able-bodied individuals during loaded gait and some results were novel and surprising. As mentioned previously, all comparisons with able-bodied individuals are from literature.

5.1 Level Ground

Changes to both kinematic and kinetic test variables were found between WP and WOP conditions. However no significant changes in temporal-spatial parameters occurred.

In the literature, increasing pack weight shortened step length, increased stride rate, increased double limb support time, and decreased swing phase for able-bodied individuals. In this thesis, none of these outcomes were significant on level ground and the differences between means for WP and WOP were minimal. However, some of the literature [18, 19, 27] reported no significant differences in temporal-spatial parameters on level ground between pack and no-pack conditions, which was attributed to participants self-selecting their pace (i.e., setting a fixed pace led to temporal-spatial deviations as the participant accommodated to an unnatural walking speed).

Although there were no significant differences in temporal-spatial parameters, there were differences in kinematic and kinetic test variables with the addition of the weighted pack. Pelvis axial rotation range significantly decreased when a backpack weight was added. This is most likely due to a reduction in rotational movement in the pelvis in order to increase stability and that the weight of the pack limits rotational mobility. The decreased rotation range could also be a consequence of the backpack's hip belt, which provides a flexible link between the pelvis and the trunk that could restrict motion between the pelvis and trunk. Both maximum pelvic obliquity and maximum pelvis axial rotation angular velocity notably decreased, with the greater decrease in axial rotation. Both decreases can be attributed to a need to make slower and more methodical pelvis movements while the pack is worn. The greater decrease in axial rotation angular velocity was related to the significant decrease in pelvis axial rotation range.

On the intact limb, a notable decrease in ankle plantarflexion at weight acceptance was found when walking across level ground with a pack. While not statistically significant, step length decreased by an average of 2-3 cm, possibly contributing to the decrease in plantarflexion. Since the steps were shortened, the foot landed closer to the body's center of gravity allowing for less plantarflexion at foot-flat.

Knee angle during weight acceptance increased by approximately four degrees under the weighted pack condition on the intact limb. As the limb exits swing phase, the extra total body momentum caused by the pack's weight needs to be absorbed. Knee flexion upon weight-bearing is a common strategy for accommodating such loads [18, 20, 24]. Although not significant or notable, the increased eccentric knee extension moment and KP1 power burst would support this argument. In fact, the KP1 power burst almost doubled with the addition of the weighted pack. The knee angular velocity at weight acceptance also significant increased because a greater range of motion occurred without a subsequent increase in overall stance time. To overcome the greater knee flexion following weight acceptance and return to the normal knee extension angle at midstance, a notable increase in the WP KP2 power burst occurred. During swing, intact limb knee flexion decreased (i.e., the knee was more extended) with the addition of the weighted pack; however, the difference was minimal and only occurred for 6 of 10 subjects (four subjects had more knee flexion during swing). Intact limb hip flexion (WP) during weight acceptance notably increased by ten degrees over the WOP condition. This increase in flexion is a weight acceptance mechanism used in conjunction with the previously mentioned increase in knee flexion.

On the prosthetic limb, ankle dorsiflexion was significantly greater before push-off when wearing the weighted pack. Since the prosthetic foot-ankle unit is a rigid body, differences between the two conditions is most likely due to increased foot-ankle deformation from the extra pack weight. The corresponding angular velocity also had a significant increase due to an increased range of motion occurring over the same time. There was no significant difference in prosthetic limb step time, so an increased range of motion over the approximate same amount of time leads to increased angular velocity.

Plantarflexion angular velocity at push-off also displayed a notable increase. Kinetically, the prosthetic ankle had a significant increase in the maximum plantarflexion moment. This increased moment led to a plantarflexion angular acceleration increase at push-off, which cause the noted increase in plantarflexion angular velocity.

While no significant or notable kinematic changes were found at the knee on the prosthetic side, the KP3 power burst for WP was significantly greater than WOP. This power burst is the energy absorbed by the knee extensors to control knee flexion in late stance and early swing. Since a notable increase in hip flexor power (HP3) was found for WP, a larger KP3 peak power is required to control knee flexion. This increased power burst can also be directly attributed to the weighted backpack.

On the prosthetic side, hip flexion at weight acceptance averaged ten degrees more under the weighted pack condition, the same approximate increase seen on the intact side. This increase in flexion can be attributed to the pack weight and the load bearing during weight acceptance. Hip flexion angular velocity during weight acceptance subsequently increased because of the larger range of motion with minimal change in overall stride time.

Maximum hip flexion moment was significantly greater for the backpack condition. This increased hip flexor moment was necessary to complete toe-off and enter swing phase while carrying more weight. The hip flexors perform concentric work to flex the hip and lift the knee, helping to lift the foot off the ground and initiate swing. Both HP2 and HP3 power bursts were significant greater when the backpack was worn. The HP2 power burst is eccentric work being done by the hip flexors to decelerate the backwards rotating thigh. HP3 is concentric work being done by the hip flexors to lift the limb upwards and forwards. Therefore, with the addition of a weighted pack, there is an increase in both energy absorbed and generated by the hip flexors to transition mid-stance to early swing.

More significant differences in angles occurred for the intact limb and a greater number of differences in angular velocity occurred for the prosthetic limb. These two findings can be explained by a need to move the prosthetic limb faster (slightly higher strides/minute) to a more stable position while the intact limb is relied on to accommodate the pack weight.

Consistent with the literature on able-bodied weighted pack gait, knee flexion at weight acceptance and hip flexion at weight acceptance increased with backpack loads. An increase in ankle angle, knee extension, and hip extension at foot-off, as noted in the literature, were not observed on level ground in this experiment [18, 20, 24].

5.2 Uneven Ground

On uneven ground, both temporal-spatial parameters and kinematic test variables differed between WP and WOP for the intact limb. No significant or notable changes occurred on the prosthetic side for temporal-spatial variables and only a few differences were found for kinematic test variables.

Stride length was significantly shorter with the addition of the weighted pack. The participants would have shortened their stride length to increase stability and decrease risk of falling.

Pelvic axial rotation range significant decreased when wearing the backpack. The added weight would cause the participant to limit movement and rotation at the pelvis in order to maintain stability. As with level ground, the backpack's hip belt could also limit rotational movement at the pelvis. Absolute maximum trunk axial rotation velocity decreased significantly by approximately 25 degrees/s with the addition of the backpack. Slower trunk movements and slower movements in general, can lead to increased stability.

Intact limb step length significantly decreased for the WP condition. With no significant change in prosthetic step length, participants could rely on their intact limb more to accommodate for the load. Intact stride length was also significantly lower, which is understandable due to the decrease in step length. Intact limb swing time also decreased with the addition of the weighted pack. This decrease in swing time is also used to increase stability by reducing the time in prosthetic single limb support, and also demonstrates an amputee's reliance on their intact limb.

Intact limb ankle plantarflexion angle during weight acceptance was significantly smaller with the addition of the weighted pack. This is a direct cause of the shorter step length described in the above paragraph. If the foot does not reach as far in front of the body, upon completion of the step, the ankle will be less plantar flexed.

The intact limb's knee was more flexed during weight acceptance, as previously seen on level ground and on the prosthetic limb. The associated knee angular velocity was also greater for the WP condition than the WOP condition. It should be noted that WP knee flexion angular velocity was greater during initial swing while knee extension angular velocity during terminal swing was notably lower. With the backpack, the knee flexed faster to provide foot clearance more quickly. Slower extension angular velocity could provide better foot position control before heel-strike and eventually weight acceptance. The increased knee flexion angular velocity during swing could also contribute to the previously mentioned decrease in swing time.

The hip was more flexed during swing initiation under the WP condition for the intact limb. This increase in hip flexion can increase foot clearance. As seen on level ground and the prosthetic limb, hip flexion during weight acceptance was approximately ten degrees greater, to accept the pack and body weight and possibly to have the trunk closer to the base of support at weight acceptance. The associated hip angular velocity also resulted in a notable increase because the range of motion increased but time did not.

As mentioned earlier, there were no significant or notable differences in temporal-spatial parameters for the prosthetic limb; however, there were changes in kinematic test variables. As observed in level ground, an increase in both ankle dorsiflexion before push-off and the subsequent angular velocity were observed on uneven ground. These increases were similar to level ground and thus similar reasons for the changes can be inferred; deformation of the prosthetic foot due to the weight of the backpack.

On the prosthetic side, the knee exhibited significantly greater flexion at weight acceptance for WP. This increase in knee flexion helps to absorb the increased forces caused by the pack weight. Knee flexion angular velocity during swing was shown to significantly increase when comparing the WP condition to the WOP pack condition. Since the temporal-spatial parameters had no significant or notable changes, the main function of the increased knee flexion angular velocity during swing would be to allow the foot to clear the ground faster.

Like level ground and the intact limb on uneven ground, the prosthetic limb also had a significant increase in maximum hip flexion angle during weight acceptance. A similar increase of 11 degrees was seen on the uneven ground surface, as compared to the approximate 10 degree increase on level ground. As with level ground, this increase can be attributed to load bearing during weight acceptance.

On both limbs, the knee and hip were more flexed during weight acceptance when wearing the pack. These differences were also seen on level ground. Knee angular velocity was also affected by the uneven ground surface since more test variables were either significantly or notably different than the level ground test variables. The greater number of test variables differences than level ground is an indicator that uneven ground required more adaptations to successfully complete the task when wearing a backpack load. Since these knee and hip angle differences were found for both limbs, the adaptation threshold for the intact limb may have been surpassed, thereby requiring changes to the prosthetic limb gait patterns. As reported in Kendell et al. [71], intact limb gait patterns typically change to adapt to different surfaces while prosthetic limb patterns are optimized to minimize such changes.

5.3 Ramp Up

The temporal-spatial literature is inconclusive in regards to walking up an incline. Han et al. [30] reported that, for inclines above eight percent (the ramp in this thesis had an eight degree incline, 14.05 percent), step time and double-support time increased while velocity and cadence decreased. In addition, stride length and duration increased as incline increased [31]. In agreement with Han et al. [30], McIntosh et al.

[33] also reported that cadence decreased; however, velocity increased. Lay et al. [34] found no significant changes to stride length or stride duration, also in contradiction with Han et al. [30].

Walking speed significantly decreased with a pack, likely to increase stability due to slower overall movements. Since ramp up was the only surface to show a decrease in overall walking speed, and produced the most significant differences in temporal-spatial parameters, it can be surmised that ramp up was the more difficult surface out of the four tested, requiring more changes to for safe mobility. Statures per second, walking velocity normalized for height significantly increased and stride length decreased. Shorter steps are consistent with these outcomes and are a strategy for improving stability. Lastly, double limb support time significantly increased. People are more stable with both feet on the ground, therefore increasing double-support is another stability enhancing strategy. These temporal-spatial findings are in line with Han et al. [30] and are contradictory to McIntosh et al. [33] and Lay et al. [34].

Both trunk axial rotation range and maximum angular velocity were lower for the WP condition. By limiting movement and reducing the speed of movement at the trunk, stability is increased. Trunk motion may also have been minimally restrained by the backpack's waist belt, but this effect was likely small as compared with the weight effect.

Intact limb WP stance time was notably longer than WOP. As previously shown on other surfaces, participants displayed increased reliance on their intact limb to accommodate to the duress of the pack weight. There was also a significant decrease in intact limb step length when comparing the WP condition to the WOP condition. A shorter step keeps the center of gravity inside the area of support ensuring increased stability. Stride length also displayed a significant decrease with the addition of the pack weight for the same reasons that step length decreased. This decreased stride length, also noted on the prosthetic side, is also in line with Han et al. [30] but contradictory to Lay et al. [34].

Both WP ankle dorsiflexion during weight acceptance and WP dorsiflexion before push-off increased significantly for the intact limb. In contrast to the level surfaces, the ankle was not plantarflexed during weight acceptance due to the incline. The increased dorsiflexion during weight acceptance could be a consequence of the shorter step length. Between load conditions, the increased dorsiflexion before push-off could be a consequence of the participants needing to use the ankle to help maintain stability, thereby increasing double-support time and hence greater dorsiflexion at terminal stance. On all surfaces, increased hip flexion and knee flexion helps to accommodate the combined weight of the body and backpack; however ramp up was the most difficult surface, since it elicited the most test variable changes. Leaning forward at the hip and flexing the knee was not enough to accommodate the increased weight during stance and the ankle strategy needed to be employed as well. Walking up a ramp was the most difficult surface and both the ankle and hip balance strategies were needed to accommodate the weight of the pack on the intact limb.

The intact limb knee during weight acceptance was notably more flexed for WP, as seen on other surfaces, in order to absorb the increased weight upon impact with the ground. Knee extension angle before push-off significantly decreased with the addition of the weighted pack. The decrease in extension before push-off could be because the increased pack and body weight is more difficult to lift up the ramp. Extension angular velocity during swing also had a notable decrease. This decrease in movement speed would allow for a more controlled entrance into stance.

As seen previously, maximum hip flexion at weight acceptance was approximate ten degree greater for WP, helping to accommodate for pack weight during weight acceptance.

Both prosthetic step and stride length were significantly lower for WP during ramp ascent. The decrease in step and stride length could increase stability, as mentioned earlier in this discussion. The decrease may also help reduce the work required for each step by limiting vertical movement; however, without kinetic data for this surface this hypothesis cannot be proved. In accordance with the study by Vickers et al. on elderly unilateral transtibial amputees [72], the prosthetic limb displayed shorter single stance time than the intact limb.

Maximum prosthetic ankle plantarflexion during weight acceptance was significantly less, while maximum ankle dorsiflexion before push-off was significantly greater, for the weighted pack condition. The decrease in ankle plantarflexion could be attributed to the decrease in step length when wearing the backpack. The prosthetic limb differed from the intact limb, which was dorsiflexed during weight acceptance, due to the longer step length on the prosthetic side. Between conditions, the increased ankle dorsiflexion on the prosthetic side can be directly attributed to deformation of the foot-ankle prosthesis, as seen on the other surfaces.

WP knee flexion on the prosthetic side was significantly greater during weight acceptance. This increase in flexion can be attributed to increased load accommodation. Knee extension angular velocity during swing decreased significantly, most likely to enable more controlled and deliberate movement as the limb exits swing phase and enters weight acceptance.

Hip extension was significantly lower at push-off and hip flexion was significantly greater at weight acceptance on the prosthetic side. The decrease in hip extension could be due to the foot or limb leaving the ground while it is still underneath the upper body. The increase in hip flexion, which was also reported on the other surfaces and each limb, helps to absorb the weight of the pack as the limb comes into contact with the ground.

As seen in the literature on ramp ascent, all three lower limb joints had greater flexion when compared to level ground walking. Contrary to the article written by Vrieling et al. [36], when comparing prosthetic and intact limbs, greater hip and knee flexion during weight acceptance and decreased hip extension at push-off on the prosthetic limb were not found. The population from Vrieling et al. [36] varied widely in terms of Amputee Activity Score (M=33.8, SD=26.1), indicating that the population was different than the K4-level population in this thesis. Also, the Vrieling population sample included six traumatic and six oncology and vascular amputees, compared to the study sample of ten traumatic amputees that likely had fewer comorbidities. The lower activity level people may have required increased flexion to accomplish the ramp ascent task.

5.4 Ramp Down

Incline walking research is sparse and lacks unanimous conclusions. From Leroux et al. [31], stride length and stride time for able-bodied participants decreased when walking downhill. However, Redfern and DiPasquale [32] noted that the ramp decline must be greater than ten degrees to achieve the same results. Lay et al. [34] found that stride length and stride time showed no changes when walking downhill. The literature reported that each lower limb joint was more extended when walking downhill, from mid-swing to early stance, followed by greater knee flexion during stance in order to lower the body. For amputee gait, Vrieling et al. [36] noted an increase in knee flexion during late stance and swing, and a decrease in hip extension in late stance on the prosthetic limb. Vickers et al. [72] reported that transtibial amputees displayed less dorsiflexion at heel-strike and more dorsiflexion at toe-off when compared to able-bodied controls; however, the lack of ankle plantarflexion during ramp descent brings these outcomes into question. Reduced knee flexion during swing, when compared to controls, was also noted.

Qualitatively, participants were the least comfortable with the ramp descent task. This is in contrast to the ramp up task being the most biomechanically difficult. Double limb support time significantly increased when walking down a ramp, after the addition of a weighted pack. The increase in double limb support time ensures the participant's stability is maintained.

Both WP trunk abduction/adduction and WP axial rotation ranges were notably lower on the ramp down surface. It is possible that the minimal pelvic strap on the backpack limited trunk movement. Also four angular velocities were also significantly or notably less when comparing the WP and WOP conditions. Absolute maximum pelvic axial rotation, trunk flexion, trunk abduction/adduction, and trunk axial rotation angular velocities all decreased with the addition of the backpack. By slowing and limiting movement, those movements become more controlled and allow for increased stability and possibly more confident gait.

WP intact limb stance time significantly increased when compared to the WOP condition. Stability is maintained by keeping the limb on the ground longer.

The intact limb knee was more extended during swing, when comparing WP and WOP. The decreasing surface slope combined with flexion would move the foot further from the surface before heel-strike. By reducing knee flexion during swing, the foot stays closer to the inclined surface for the duration of the step, possibly enhancing gait confidence. The more extended knee may also relate to centre of mass position with the weighted pack, requiring additional extension to maintain the body-pack centre of mass position for forward momentum [72].

Prosthetic limb stance time increased significantly with the addition of the backpack weight, which was related to the increase in double-support time. Again, by keeping the limbs on the ground for longer, stability is maintained. However, prosthetic limb stance time was still shorter than the intact limb, further displaying amputee’s reliance on their intact limb for control. Both prosthetic step length and stride length notably decreased when comparing the WP and WOP conditions. The notable decrease in prosthetic step length without a subsequent decrease on the intact limb further displays amputee's confidence in their intact limb and reliance on this limb to maintain stability.

On the prosthetic side, both ankle plantarflexion at weight acceptance and dorsiflexion had significant changes for WP. Ankle plantarflexion significantly increased, but by less than one degree. Ankle dorsiflexion before push-off also significantly increased under the backpack condition. Both of these increases can be attributed to deformations in the prosthetic foot-ankle due to the pack weight. The ramp angle and the direction of movement allowed the foot to be deformed into a more plantar flexed position at weight acceptance. The reason that the plantarflexion would have been significant is due to the uniformity of the difference in means for the various prosthetic feet.

The prosthetic knee flexion angle during weight acceptance decreased when comparing the WP condition to the WOP condition. This is a different change compared to the previous three surfaces. The decrease in flexion could be attributed to a fear of falling. The knee is already more flexed while going down a ramp and more flexion would bring the center of gravity closer to the heels of the foot and may lead to an increase chance of falling. When the backpack was worn knee angle before push-off, which due to the ramp was in flexion, displayed a significant decrease, or became more extended. An increase in extension could be a consequence of the pack weight and needing more energy to lift the body, however this is unconfirmed without kinetic data.

On the prosthetic limb, maximum hip flexion angular velocity during weight acceptance significantly increased. This increased speed was related to the increase in hip flexion, producing a larger range of motion, which happens in approximately the same time (i.e., no significant overall change in step time or swing time). Therefore the hip has to move a greater distance in the same time, leading to an increased angular velocity.

Similar to ramp up, trunk axial rotation range decreased in order to maintain stability. Unlike the other surfaces, an increase in knee flexion and hip flexion at weight acceptance were not noted on both limbs. The prosthetic limb exhibited more test variable changes than the intact limb. Although the intact limb's knee was more extended during swing, implying that the intact foot is kept nearer to the ground, enhancing gait confidence.

As with the transtibial amputee gait literature on inclined walking, the study participants had decreased hip extension before push-off and increased knee flexion during stance on the prosthetic side for the ramp down surface, when compared to level ground walking. Also in agreement with Vrieling et al. [36], knee flexion increased during swing.

5.5 Prosthesis Evaluation Questionnaire

The participants had similar responses on their prosthesis evaluation questionnaire (PEQ). However participant one's score on the well-being subscale was an outlier (i.e., lower than eight of the other participants) and participant three had outliers on the perceived response, social burden, and well-being subscales (i.e., less than nine of the other participants). It should be noted that participant three had the prosthetic foot in the greatest state of disarray due to neglect and improper care. It is possible that, had the participant replaced the prosthesis with a newer one, the scores on the PEQ subscales may have been higher.

The only high strength Pearson correlations were for level ground; WP pelvis axial rotation range, WP absolute maximum pelvis axial rotation angular velocity, and WP absolute maximum trunk axial rotation angular velocity. Therefore, participants that had lower ambulation scores exhibited higher axial range of motion at the pelvis and higher absolute maximum pelvis and trunk axial rotation angular velocities. This may indicate that people with lower ambulatory capabilities have more difficulty controlling the pelvis and trunk when wearing a backpack load.

There were no correlations greater than or equal to 0.7 for the residual limb health PEQ subscale. Uneven ground had only one correlation of moderate strength or higher, and that was pelvis axial rotation range for the WOP condition. The majority of relevant correlations were for the knee, pelvis, and trunk joints. Of the 18 correlations of at least moderate strength for the ambulation subscale, only 5 did not involve the knee, pelvis, or trunk. The residual limb health subscale had a total of 14 correlations of at least a moderate strength level, with only one that did not involve the knee, pelvis, or trunk joints.

All of the pelvis and trunk correlations had a negative relationship. Participants that scored higher on either of the PEQ subscales exhibited smaller ranges of motion and slower movements. The knee had all positive correlations, on both subscales. Therefore, the more confident and pain free participants had larger knee angles for both limbs and conditions. As stated previously, participants controlled movement at the pelvis and trunk and increased flexion at the knee during weight acceptance in order to accommodate the load.

5.6 Comparison to Able-Bodied Individuals

5.6.1 Temporal-spatial Parameters

The most common temporal-spatial changes as load increases are a decrease in step length and swing phase, and an increase in stride rate and double stance time [1, 19, 20, 21, 22, 23, 24]. Single stance time does not change.

In this thesis, none of the significant or notable temporal-spatial differences between WP and WOP were common to all four surfaces. In fact, no significant changes to temporal-spatial parameters were seen on level ground. This lack of change on level ground in is agreement with Atwells [18], in reference to articles by Charteris [19] and Harmen et al. [27]. Possibly, no changes in self-selected pace were required for familiar surface like level ground and, as a gravitational load; the backpack load did not limit level ground progression. Ramp up elicited the most temporal-spatial parameters changes, and consequently the most changes overall. Also, none of the surfaces had significant or notable outcomes for all of these parameters from the literature (step length and swing phase, and an increase in stride rate and double stance time).

Stride rate, or more specifically statures per second, was lower while walking up the ramp with the addition of the pack, contrary to the literature on able-bodied-level-ground gait. Ramp up is the most difficult surface because it elicited the most gait changes, Therefore, a slower stride rate would lead to more controlled movements.

A shorter WP swing phase was only found on the intact limb on uneven ground. By shortening the intact limb's swing phase, the foot is in the air for a shorter amount of time, allowing the more "confident limb" to be in contact with the ground sooner.

In the literature, there was no change in single stance time with the addition of a pack, on level ground [1, 19, 21]. However, intact limb stance time increased for walking up and down a ramp. Stability is enhanced by increasing the time the intact limb is in contact with the ground.

5.6.2 Kinematics

The most common changes to able bodied kinematics with the addition of a weighted pack, as outlined by the literature, are: an increase in knee and ankle angles, specifically an increase in plantarflexion at foot-off; an increase in knee flexion during weight acceptance; and an increase in knee extension during foot-off. At the hip, greater flexion during weight acceptance and extension during foot-off were noted [18, 20, 24].

A significant increase in plantarflexion at foot-off was not seen on any of the surfaces. Increased knee extension during foot-off was not seen consistently on any surface or limb. The increase only occurred on the prosthetic limb when walking down a ramp. Knee extension changed on ramp ascent as well; however, contrary to the literature, the change was a decrease in extension. Most likely, the knee was more flexed due to the increased pack weight and a need to keep the center of gravity over the base of support.

A significant increase in hip extension at foot-off with increased load was seen, although not consistently. This increase was seen notably on uneven ground on the intact limb and significantly on ramp ascent on the prosthetic limb.

Although the differences noted in the literature were not consistent on each limb across all surfaces, some differences were not noted in the literature. WP ankle plantarflexion decreased consistently across three surfaces for the intact limb, during weight acceptance, potentially a consequence of a decrease stride length in order to improve stability on the more confident limb. WP ankle dorsiflexion during weight acceptance on the prosthetic limb displayed a significant increase on every surface, most likely due to deformation of the prosthetic ankle-foot.

At the knee, flexion during weight acceptance increased across three surfaces on the intact limb (level ground, uneven ground, and ramp up) and two surfaces for the prosthetic limb (uneven ground and ramp up). The changes were all of a similar amount and helped to accept the increased pack weight and to maintain stability.

Hip flexion during weight acceptance also consistently increased on all surfaces, except ramp down. Similar changes were seen on both limbs for each surface. This increase in hip flexion was directly caused by the increased pack weight during weight acceptance. More momentum must be absorbed due to the increased force created by the weighted backpack.

Lastly, maximum trunk axial rotation angular velocity, which was not mentioned in the literature, had a significant decrease across all four surfaces. The decrease in trunk rotation speed occurs in order to increase stability of the upper body during movement.

Chapter 6. Conclusion

The outcomes from this thesis showed that, with the addition of a weighted pack, amputees had some differences in common with able-bodied individuals and some novel alterations to gait. However, the biomechanical differences between the amputee results and able-bodied information in the literature were mainly related to asymmetries between limbs. From the results of this study, K4-level unilateral transtibial amputees can bear a backpack weight as well as able-bodied individuals for the tested walking tasks.

Two of the most common changes seen in the thesis were an increase in prosthetic ankle dorsiflexion and an increase in hip and knee flexion during weight acceptance. The difference in prosthetic ankle dorsiflexion was seen on all four surfaces and was directly caused by the weight of the pack. Ankle-foot prosthetic deformation could lead to decreased performance at larger backpack weights, depending on the foot design. Increased hip and knee flexion during weight acceptance was seen on three of the surfaces and is a common method of dissipating forces on initial contact with the ground, as seen with able-bodied individuals.

Out of the four surfaces, from a biomechanical perspective, ramp up was the most difficult surface because it elicited to the most changes to transtibial amputee gait. However, most participants perceived that ramp down was the most difficult task.

6.1 Hypotheses

This section outlines the original hypotheses and whether the hypotheses were proven or refuted.

6.1.1 Compared to Able Bodied Gait and Unloaded Gait

1. A backpack load will not produce any significant changes in temporal-spatial parameters of an amputee's gait pattern.

   The hypothesis is mostly refuted. Many significant and notable changes to temporal-spatial parameters were found across three of the surfaces, uneven ground, ramp up, and ramp down. There were no significant or notable changes to temporal-spatial parameters of amputee gait on level ground.

2. A backpack load will not produce any significant changes in ankle, knee, and hip angles when compared to able bodied gait.

   Significant differences in ankle, knee, and hip angles were found for the amputee test population that are not common to the literature on able-bodied loaded gait. Therefore the second hypothesis was refuted. Novel WP amputee gait changes were also seen, greater prosthetic ankle dorsiflexion before foot-off and lower intact limb plantarflexion during weight acceptance. Also, maximum trunk axial rotation angular velocity was significantly lower across all four surfaces, a result that was not reported in the literature.

3. A backpack load will not produce a significantly greater maximum ankle dorsiflexion moment during level ground walking.

   No significant changes were found for ankle dorsiflexion moment on either limb during level ground walking, therefore the third hypothesis was proven.

4. A backpack load will not produce greater net joint powers during level ground walking. Specifically, HP3 and KP2 power bursts will not be greater than the unloaded position.

   The HP3 and KP2 power bursts were not significantly greater with the addition of the weighted pack on either limb across level ground walking, although there were significant changes to the KP3 and HP2 power bursts on the prosthetic limb. These changes could have occurred to compensate for the lack of ankle joint on the prosthetic side. This hypothesis was rejected.

5. There will be no changes to gait and stability found when comparing between surface changes.

   Each surface did not evoke the same changes to gait and stability between WP and WOP. When counting the parameters that had significant or notable differences in kinematics and temporal-Spatial parameters, ramp ascent had 23 parameters (9 temporal-Spatial and 14 kinematic changes to gait), uneven ground had 19 parameters (4 temporal-Spatial and 15 kinematic), ramp down had 18 parameters (5 temporal-Spatial and 13 kinematic), and level ground had 14 parameters (14 kinematic). Also walking up a ramp had the most parameters with only significant changes to temporal-Spatial parameters and kinematics (20), while ramp down had the least number of only significant changes (12). A greater number of significant-notable parameters implies a more difficult surface, that requires more gait deviations to accomplish the task. Therefore the hypothesis was refuted and ramp ascent was more difficult than the other three surfaces. Level ground was the easiest, which is understandable because it is the most familiar surface and the backpack is moved along a level surface (i.e., no larger change in potential energy due to vertical displacement).

6.1.2 Compared to the Intact Leg

1. The amputated leg will not produce significantly different joint angles when compared to the intact leg.

   Two test variables that consistently resulted in differences on different surfaces and both limbs were maximum knee flexion and maximum hip flexion angle at weight acceptance. Neither was significantly different when compared between limbs. Therefore the first hypothesis was proven. However, the prosthetic values for knee angle during weight acceptance were lower than the values for the intact limb (not significant). Since few test variables on each surface had significant or notable changes for both limbs, comparison between limbs was difficult.

2. The hip extensor and knee flexor moments will not be significantly greater on the amputated leg when compared to the intact leg.

   The hip extensor and knee flexor moments were not significantly different when comparing the amputated leg to the intact leg, therefore the second hypothesis was proven. It should be noted that, although the differences were not significant or notable, the intact limb had higher values than the prosthetic limb for maximum hip extensor moment.

3. Hip power will not be significantly greater on the amputated leg to compensate for the lack of an ankle joint.

There was no significant difference between the two limbs for all three hip power bursts on level ground walking. Therefore the hypothesis was proven.

6.2 Suggestions

Studies have been completed on how an able bodied individual can optimally carry a heavy load, as referenced in the load-bearing gait literature review section. Although future studies are required for confirmation, a double pack system (Figure 16) could create a gait pattern closer to unloaded gait by distributing the weight equally in the front and back of the body [1, 20, 73]. However a double backpack can create problems outside of the realm of gait biomechanics, such as heat exchange. Backpack frames and a hip belt can also be used to reduce loads on the shoulders, reduce muscle fatigue, and reduce perceived strain. It is also important to properly fit a backpack, using a pack with sufficient adjustment possibilities, to optimize the wearer's comfort and function [1].

Figure 16: Double backpack system.

An article by Fradet et al. [74] noted that a prosthetic ankle that enabled transtibial amputees to walk in a more physiologic manner leads to knee kinematic improvements during ramp ascent and an increased feeling of safety while walking downhill. A single axis foot can also allow for more gait symmetry between limbs and is beneficial for higher activity levels on inclines and uneven terrain at various velocities

[75]. Proper alignment and fitting is also an important consideration [76], therefore evaluating prosthetic fit with the person wearing their typical gear may be beneficial before extended use of backpack loads in the workplace or before deployment.

6.3 Future Research

Being an exploratory study and novel experiment, there are many possibilities for future studies. Future studies can use the reported p-values from this thesis to specify what variables to investigate. By narrowing the number of test variables, the Bonferroni correction would be lowered and more variables could produce significant findings.

Studies performed with different amputation levels, female amputees, and lower K-levels would help to widen the current knowledge base of backpack-load gait.

A study with a higher pack weight, closer to that carried by active duty personnel and not just for marching duties, and research on fatigue effects would help gain a more complete understanding of how pack weight can affect the gait of individuals with lower extremity amputations.

Lastly, being able to analyze gait kinetics on different surfaces would be beneficial. Possibilities include adding force plates measurements for uneven ground and ramp surfaces or creating new virtual reality environments using systems such as CAREN (Motek Medical).

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Appendix A: Test Variable Abbreviations

Table 18: Test variable abbreviation descriptions for kinematics.

Abbreviation	Test Variable
AA1	Ankle plantarflexion (weight acceptance)
AA2	Ankle dorsiflexion (before push-off)
AA3	Ankle plantarflexion (at push-off)
AAV1	Ankle angular velocity (dorsiflexion flexion after footflat)
AAV2	Ankle angular velocity (dorsiflexion before push-off)
AAV3	Ankle angular velocity (plantarflexion at push-off)
KA1	Knee angle (weight acceptance)
KA2	Knee angle (before push-off)
KA3	Knee angle (swing)
KAV1	Knee angular velocity (midstance)
KAV2	Knee angular velocity (swing flexion)
KAV3	Knee angular velocity (swing extension)
HA1	Hip angle (max extension at push-off)
HA2	Hip angle (max flexion at weight acceptance)
HA3	Hip adduction (push-off)
HA4	Hip abduction (swing)
HAV1	Hip angular velocity (max extension at push-off)
HAV2	Hip angular velocity (max flexion at weight acceptance)
HAV3	Hip adduction angular velocity (push-off)
HAV4	Hip abduction angular velocity (swing)
PR1	Pelvic tilt (range)
PR2	Pelvis obliquity (range)
PR3	Pelvic axial rotation (range)
TR1	Trunk flexion (range)
TR2	Trunk abduction/adduction (range)
TR3	Trunk axial rotation (range)
PAV1	Pelvic tilt angular velocity (absolute maximum)
PAV2	Pelvic obliquity angular velocity (absolute maximum)
PAV3	Pelvic axial rotation angular velocity (absolute maximum)
TAV1	Trunk flexion angular velocity (absolute maximum)
TAV2	Trunk abduction/adduction angular velocity (absolute maximum)
TAV3	Trunk axial rotation angular velocity (absolute maximum)

Table 19: Test variable abbreviation descriptions for kinetics.

	Test Variable
AM1	Maximum ankle moment (dorsiflexion foot slap)
AM2	Maximum ankle moment (plantarflexion transition)
AP1	Absorption by dorsiflexors after heel contact. Some people do not exhibit AP1
AP2	Generation by dorsiflexors to pull the leg forward over the foot. Some people do not exhibit AP2
AP3	Absorption by plantar flexors as leg rotates forward over foot
AP4	Generation of energy by plantar flexors at push-off
KM1	Maximum knee extension moment (weight acceptance)
KM2	Maximum knee flexion moment (midstance)
KP1	Energy absorbed by knee extensors during weight acceptance
KP2	Energy generated by knee extensors as knee extends during mid-stance
KP3	Energy absorbed by knee extensors as knee flexes during late stance and early swing
HM1	Maximum hip extension moment (foot slap)
HM2	Maximum hip flexion moment (toe-off to early swing)
HP1	Energy generated by hip extensors as hip extends (hip flexion reduces) during weight acceptance
HP2	Energy absorbed by hip flexors in mid-stance as backward-rotating thigh is decelerated
HP3	Energy generated by hip during late stance and early swing to accelerate the lower limb upward and forward

Appendix B: Temporal-Spatial Subject Data

Table 20: Level ground temporal-spatial means for ten subjects with a pack.

Temporal-spatial Parameter	1	2	3	4	5	6	7	8	9	10
cycle time (s)	1.24	1.12	1.25	1.27	1.17	1.08	1.01	1.11	1.13	1.17
speed (m/s)	1.14	1.40	1.23	1.17	1.18	1.21	1.30	1.30	1.21	1.25
statures per second	0.63	0.78	0.68	0.65	0.66	0.67	0.72	0.72	0.67	0.69
stride length (m)	1.40	1.57	1.53	1.49	1.38	1.30	1.31	1.44	1.36	1.46
stride width (m)	0.18	0.14	0.17	0.22	0.17	0.12	0.16	0.17	0.12	0.21
double limb support (s)	0.29	0.25	0.32	0.28	0.24	0.25	0.23	0.15	0.24	0.27
intact limb cycle time (s)	1.25	1.11	1.25	1.27	1.16	1.07	1.01	1.11	1.14	1.19
intact limb stance time (s)	0.77	0.70	0.82	0.82	0.73	0.68	0.64	0.65	0.70	0.74
intact limb step length (m)	0.66	0.76	0.76	0.72	0.70	0.63	0.62	0.72	0.65	0.73
intact limb step time (s)	0.59	0.55	0.61	0.59	0.57	0.52	0.48	0.52	0.56	0.57
intact limb steps per min.	101.51	109.12	98.27	102.38	105.64	114.78	125.81	115.98	107.07	105.01
intact limb stride length (m)	1.32	1.51	1.52	1.43	1.40	1.27	1.23	1.43	1.30	1.46
intact limb strides per min.	48.01	54.07	47.91	47.28	51.94	56.11	59.88	53.96	52.83	50.51
intact limb swing time (s)	0.48	0.41	0.44	0.46	0.43	0.40	0.37	0.46	0.45	0.43
prosthetic cycle time (s)	1.22	1.13	1.24	1.28	1.18	1.08	1.02	1.10	1.12	1.16
prosthetic stance time (s)	0.75	0.67	0.77	0.73	0.69	0.64	0.60	0.62	0.68	0.70
prosthetic step length (m)	0.74	0.81	0.78	0.75	0.65	0.66	0.69	0.73	0.71	0.73
prosthetic step time (s)	0.63	0.57	0.64	0.69	0.59	0.55	0.53	0.59	0.57	0.59
prosthetic steps per min.	94.83	104.91	93.26	87.67	102.62	109.82	114.13	102.30	106.03	101.99
prosthetic stride length (m)	1.47	1.61	1.55	1.50	1.30	1.31	1.38	1.45	1.41	1.45
prosthetic strides per min.	49.18	53.10	48.31	47.02	50.89	55.36	59.14	54.36	53.70	51.96
prosthetic swing time (s)	0.48	0.45	0.50	0.54	0.47	0.43	0.41	0.50	0.45	0.46

Table 21: Level ground temporal-spatial means for ten subjects without a pack.

Temporal-spatial Parameter	1	2	3	4	5	6	7	8	9	10
cycle time (s)	1.21	1.13	1.25	1.14	1.18	1.07	1.04	1.09	1.13	1.15
speed (m/s)	1.16	1.41	1.23	1.35	1.15	1.23	1.35	1.40	1.24	1.35
statures per second	0.65	0.78	0.68	0.75	0.64	0.68	0.75	0.78	0.69	0.75
stride length (m)	1.41	1.59	1.54	1.54	1.36	1.31	1.40	1.52	1.40	1.55
stride width (m)	0.21	0.15	0.16	0.22	0.15	0.13	0.17	0.20	0.14	0.22
double limb support time (s)	0.26	0.22	0.28	0.18	0.22	0.23	0.18	0.22	0.20	0.23
intact limb cycle time (s)	1.22	1.13	1.26	1.17	1.17	1.07	1.04	1.08	1.14	1.15
intact limb stance time (s)	0.74	0.69	0.81	0.69	0.71	0.66	0.63	0.68	0.68	0.70
intact limb step length (m)	0.68	0.78	0.76	0.75	0.71	0.62	0.67	0.77	0.66	0.78
intact limb step time (s)	0.59	0.55	0.61	0.54	0.59	0.53	0.49	0.52	0.56	0.56
intact limb steps per min.	101.26	108.73	98.43	111.77	102.12	114.23	122.16	115.27	106.48	107.04
intact limb stride length (m)	1.36	1.56	1.53	1.51	1.42	1.25	1.34	1.53	1.32	1.56
intact limb strides per min.	49.28	53.20	47.56	51.27	51.36	56.16	57.50	55.82	52.64	52.05
intact limb swing time (s)	0.47	0.43	0.46	0.45	0.47	0.41	0.41	0.42	0.47	0.45
prosthetic cycle time (s)	1.21	1.12	1.24	1.12	1.19	1.08	1.04	1.10	1.13	1.14
prosthetic stance time (s)	0.74	0.65	0.74	0.62	0.69	0.64	0.59	0.64	0.67	0.68
prosthetic step length (m)	0.73	0.80	0.79	0.77	0.64	0.67	0.72	0.75	0.74	0.77
prosthetic step time (s)	0.62	0.57	0.65	0.60	0.59	0.54	0.54	0.56	0.57	0.58
prosthetic steps per min.	97.46	105.67	92.11	99.94	102.43	110.40	110.60	106.55	105.28	103.24
prosthetic stride length (m)	1.45	1.61	1.57	1.54	1.28	1.35	1.44	1.50	1.49	1.53
prosthetic strides per min.	49.76	53.46	48.48	53.61	50.52	55.83	58.03	54.55	53.21	52.54
prosthetic swing time (s)	0.47	0.47	0.52	0.52	0.49	0.44	0.45	0.45	0.48	0.44

Table 22: Uneven ground temporal-spatial means for ten subjects with a pack.

Temporal-spatial Parameters	1	2	3	4	5	6	7	8	9	10
cycle time (s)	1.34	1.12	1.29	1.32	1.16	1.08	1.03	1.22	1.14	1.22
speed (m/s)	1.18	1.42	1.35	1.20	1.17	1.32	1.39	1.16	1.13	1.23
statures per second	0.65	0.79	0.75	0.67	0.55	0.73	0.77	0.64	0.63	0.68
stride length (m)	1.58	1.58	1.74	1.59	1.16	1.42	1.42	1.42	1.29	1.50
stride width (m)	0.13	0.10	0.10	0.18	0.13	0.11	0.11	0.20	0.13	0.13
double limb support time (s)	0.24	0.18	0.25	0.22	0.21	0.18	0.12	0.12	0.21	0.23
intact limb cycle time (s)	1.34	1.12	1.29	1.33	1.16	1.08	1.03	1.22	1.14	1.23
intact limb stance time (s)	0.79	0.66	0.80	0.80	0.71	0.65	0.62	0.68	0.69	0.75
intact limb step length (m)	0.74	0.74	0.85	0.75	0.56	0.70	0.65	0.71	0.61	0.77
intact limb step time (s)	0.66	0.56	0.63	0.63	0.56	0.52	0.50	0.58	0.57	0.59
intact limb steps per minute	90.60	108.01	95.71	95.37	106.99	115.04	120.94	103.19	105.95	101.76
intact limb stride length (m)	1.49	1.49	1.70	1.50	1.12	1.39	1.30	1.42	1.23	1.53
intact limb strides per minute	44.79	53.50	46.56	45.28	51.73	55.60	58.60	49.35	52.46	48.99
intact limb swing time (s)	0.55	0.46	0.49	0.52	0.46	0.44	0.42	0.54	0.46	0.49
prosthetic cycle time (s)	1.34	1.11	1.29	1.32	1.16	1.07	1.03	1.23	1.14	1.22
prosthetic stance time (s)	0.79	0.64	0.74	0.75	0.67	0.61	0.58	0.66	0.67	0.70
prosthetic step length (m)	0.84	0.84	0.90	0.83	0.59	0.73	0.78	0.71	0.67	0.74
prosthetic step time (s)	0.68	0.56	0.67	0.70	0.61	0.56	0.53	0.64	0.58	0.63
prosthetic steps per minute	87.83	107.83	90.31	86.12	99.49	108.26	113.43	93.78	104.38	95.48
prosthetic stride length (m)	1.67	1.67	1.80	1.66	1.19	1.45	1.55	1.42	1.35	1.48
prosthetic strides per minute	44.65	54.07	46.68	45.61	51.66	55.94	58.64	48.87	52.83	49.14
prosthetic swing time (s)	0.56	0.47	0.55	0.59	0.51	0.46	0.45	0.56	0.48	0.52

Table 23: Uneven ground temporal-spatial means for ten subjects without a pack.

Temporal-spatial Parameters	1	2	3	4	5	6	7	8	9	10
cycle time (s)	1.31	1.16	1.31	1.29	1.20	1.10	1.07	1.22	1.20	1.25
speed (m/s)	1.24	1.44	1.32	1.29	1.11	1.29	1.41	1.26	1.15	1.27
statures per second	0.69	0.80	0.73	0.72	0.62	0.72	0.78	0.70	0.64	0.71
stride length (m)	1.62	1.66	1.74	1.67	1.33	1.42	1.51	1.53	1.39	1.59
stride width (m)	0.16	0.11	0.13	0.19	0.10	0.11	0.13	0.16	0.14	0.13
double limb support time (s)	0.22	0.16	0.24	0.17	0.18	0.16	0.16	0.10	0.19	0.22
intact limb cycle time (s)	1.31	1.14	1.30	1.30	1.20	1.10	1.07	1.21	1.20	1.24
intact limb stance time (s)	0.77	0.67	0.80	0.75	0.71	0.65	0.63	0.68	0.70	0.75
intact limb step length (m)	0.77	0.79	0.88	0.80	0.66	0.69	0.75	0.78	0.66	0.80
intact limb step time (s)	0.65	0.57	0.64	0.62	0.59	0.54	0.52	0.58	0.59	0.60
intact limb steps per minute	92.88	105.95	94.25	96.21	102.21	112.23	116.04	103.00	101.50	99.72
intact limb stride length (m)	1.54	1.58	1.76	1.60	1.32	1.38	1.50	1.55	1.33	1.61
intact limb strides per minute	45.99	52.55	46.10	46.24	49.87	54.42	56.01	49.51	49.93	48.41
intact limb swing time (s)	0.56	0.49	0.52	0.54	0.50	0.46	0.45	0.54	0.50	0.51
prosthetic cycle time (s)	1.30	1.17	1.33	1.29	1.19	1.10	1.07	1.22	1.20	1.25
prosthetic stance time (s)	0.78	0.65	0.75	0.71	0.67	0.62	0.60	0.64	0.69	0.72
prosthetic step length (m)	0.86	0.87	0.86	0.87	0.68	0.74	0.76	0.76	0.72	0.78
prosthetic step time (s)	0.66	0.59	0.68	0.67	0.62	0.57	0.55	0.63	0.61	0.65
prosthetic steps per minute	91.88	101.43	88.94	89.46	97.69	106.08	109.05	94.94	98.40	92.88
prosthetic stride length (m)	1.71	1.73	1.72	1.74	1.35	1.48	1.51	1.52	1.45	1.56
prosthetic strides per minute	46.10	51.28	45.28	46.66	50.37	54.76	56.04	49.26	50.01	48.02
prosthetic swing time (s)	0.53	0.51	0.56	0.59	0.54	0.49	0.47	0.58	0.52	0.53

Table 24: Ramp up temporal-spatial means for ten subjects with a pack.

Temporal-spatial Parameters	1	2	3	4	5	6	7	8	9	10
cycle time (s)	1.34	1.06	1.39	1.44	1.17	1.10	1.01	1.17	1.17	1.30
speed (m/s)	1.12	1.39	1.16	0.99	1.05	1.29	1.31	1.13	1.12	1.11
statures per second	0.62	0.77	0.65	0.55	0.58	0.72	0.73	0.63	0.62	0.61
stride length (m)	1.50	1.47	1.61	1.43	1.23	1.41	1.33	1.33	1.31	1.44
stride width (m)	0.16	0.13	0.14	0.22	0.17	0.12	0.16	0.19	0.13	0.15
double limb support time (s)	0.31	0.21	0.35	0.34	0.25	0.23	0.22	0.23	0.28	0.28
intact limb cycle time (s)	1.34	1.07	1.39	1.44	1.18	1.09	1.02	1.18	1.18	1.29
intact limb stance time (s)	0.81	0.65	0.89	0.92	0.74	0.68	0.64	0.70	0.74	0.79
intact limb step length (m)	0.70	0.71	0.82	0.62	0.57	0.70	0.59	0.64	0.62	0.70
intact limb step time (s)	0.67	0.52	0.69	0.67	0.57	0.53	0.49	0.56	0.57	0.65
intact limb steps per minute	89.43	116.03	86.56	90.45	105.65	112.50	124.02	107.95	105.27	92.27
intact limb stride length (m)	1.39	1.42	1.65	1.24	1.15	1.40	1.19	1.28	1.25	1.40
intact limb strides per minute	44.91	56.04	43.27	41.93	50.76	55.00	59.00	50.92	50.83	46.48
intact limb swing time (s)	0.52	0.41	0.50	0.52	0.44	0.42	0.38	0.48	0.44	0.51
prosthetic cycle time (s)	1.33	1.05	1.39	1.45	1.17	1.10	1.01	1.16	1.16	1.30
prosthetic stance time (s)	0.85	0.62	0.84	0.87	0.70	0.65	0.61	0.70	0.71	0.79
prosthetic step length (m)	0.80	0.76	0.79	0.80	0.65	0.71	0.73	0.69	0.69	0.72
prosthetic step time (s)	0.66	0.55	0.69	0.77	0.60	0.56	0.53	0.62	0.61	0.65
prosthetic steps per minute	91.28	109.57	86.60	78.34	99.80	106.58	113.54	96.49	99.22	92.50
prosthetic stride length (m)	1.60	1.52	1.58	1.60	1.29	1.42	1.46	1.38	1.37	1.45
prosthetic strides per minute	45.04	57.07	43.25	41.42	51.54	54.75	59.64	51.64	51.79	46.18
prosthetic swing time (s)	0.50	0.44	0.54	0.58	0.48	0.45	0.41	0.47	0.46	0.52

Table 25: Ramp up temporal-spatial means for ten subjects without a pack.

Temporal-spatial Parameters	1	2	3	4	5	6	7	8	9	10
cycle time (s)	1.31	1.09	1.31	1.36	1.12	1.08	1.06	1.14	1.19	1.27
speed (m/s)	1.18	1.49	1.29	1.17	1.17	1.38	1.45	1.32	1.20	1.19
statures per second	0.65	0.83	0.72	0.65	0.65	0.77	0.81	0.73	0.66	0.66
stride length (m)	1.55	1.62	1.69	1.59	1.31	1.50	1.54	1.51	1.43	1.51
stride width (m)	0.17	0.13	0.13	0.18	0.13	0.11	0.14	0.18	0.13	0.15
double limb support time (s)	0.27	0.21	0.28	0.24	0.21	0.20	0.19	0.13	0.22	0.25
intact limb cycle time (s)	1.32	1.08	1.33	1.35	1.14	1.08	1.06	1.14	1.18	1.27
intact limb stance time (s)	0.78	0.66	0.82	0.83	0.70	0.65	0.63	0.65	0.73	0.75
intact limb step length (m)	0.72	0.78	0.83	0.74	0.64	0.73	0.72	0.75	0.68	0.73
intact limb step time (s)	0.64	0.55	0.64	0.64	0.54	0.54	0.52	0.54	0.58	0.64
intact limb steps per minute	94.55	109.71	93.47	93.26	111.85	111.38	116.37	112.29	104.40	94.00
intact limb stride length (m)	1.43	1.56	1.67	1.48	1.28	1.45	1.43	1.50	1.36	1.46
intact limb strides per minute	45.58	55.36	45.32	44.47	52.75	55.47	56.85	52.80	50.94	47.24
intact limb swing time (s)	0.52	0.43	0.50	0.54	0.44	0.43	0.43	0.48	0.47	0.52
prosthetic cycle time (s)	1.31	1.09	1.30	1.36	1.11	1.09	1.07	1.14	1.20	1.27
prosthetic stance time (s)	0.80	0.64	0.79	0.77	0.64	0.63	0.61	0.62	0.69	0.77
prosthetic step length (m)	0.83	0.84	0.86	0.84	0.65	0.77	0.83	0.76	0.75	0.78
prosthetic step time (s)	0.68	0.54	0.67	0.72	0.58	0.55	0.55	0.61	0.62	0.63
prosthetic steps per minute	88.14	110.31	89.80	84.01	103.48	109.99	109.73	98.74	96.78	94.99
prosthetic stride length (m)	1.67	1.69	1.72	1.69	1.30	1.54	1.65	1.53	1.50	1.56
prosthetic strides per minute	45.86	54.94	46.19	44.18	53.93	55.32	56.34	52.58	49.95	47.18
prosthetic swing time (s)	0.50	0.45	0.53	0.59	0.48	0.45	0.45	0.52	0.50	0.50

Table 26: Ramp down temporal-spatial means for ten participants with a pack.

Temporal-spatial Parameters	1	2	3	4	5	6	7	8	9	10
cycle time (s)	1.25	1.05	1.30	1.29	1.08	1.01	0.98	1.10	1.14	1.16
speed (m/s)	1.13	1.44	1.07	1.10	1.02	1.27	1.42	1.11	1.13	1.22
statures per second	0.63	0.80	0.56	0.63	0.59	0.72	0.86	0.65	0.68	0.69
stride length (m)	1.40	1.50	1.40	1.43	1.10	1.28	1.40	1.22	1.30	1.42
stride width (m)	0.15	0.10	0.15	0.22	0.16	0.13	0.12	0.16	0.12	0.17
double limb support time (s)	0.25	0.20	0.32	0.25	0.26	0.16	0.21	0.20	0.22	0.23
intact limb cycle time (s)	1.24	1.05	1.30	1.29	1.08	1.01	0.98	1.10	1.14	1.16
intact limb stance time (s)	0.75	0.65	0.83	0.79	0.69	0.61	0.61	0.66	0.70	0.71
intact limb step length (m)	0.68	0.73	0.70	0.69	0.60	0.62	0.69	0.58	0.64	0.75
intact limb step time (s)	0.62	0.51	0.64	0.64	0.54	0.49	0.48	0.54	0.56	0.58
intact limb steps per minute	97.21	117.71	93.31	94.57	112.43	122.50	125.37	111.32	107.20	103.27
intact limb stride length (m)	1.35	1.45	1.40	1.39	1.20	1.23	1.37	1.15	1.28	1.51
intact limb strides per minute	48.33	57.09	46.21	46.45	55.41	59.69	61.04	54.59	52.73	51.88
intact limb swing time (s)	0.50	0.40	0.47	0.49	0.38	0.40	0.37	0.43	0.45	0.45
prosthetic cycle time (s)	1.25	1.04	1.30	1.29	1.08	1.01	0.99	1.10	1.15	1.16
prosthetic stance time (s)	0.75	0.60	0.79	0.75	0.65	0.56	0.59	0.63	0.67	0.67
prosthetic step length (m)	0.72	0.78	0.69	0.74	0.50	0.65	0.71	0.64	0.66	0.67
prosthetic step time (s)	0.63	0.54	0.65	0.65	0.55	0.52	0.50	0.56	0.58	0.57
prosthetic steps per minute	95.94	110.58	91.97	92.73	110.15	115.71	119.10	107.10	102.79	104.66
prosthetic stride length (m)	1.44	1.56	1.38	1.47	1.00	1.31	1.42	1.27	1.31	1.33
prosthetic strides per minute	48.10	57.61	46.11	46.57	55.79	59.50	60.89	54.61	52.18	51.89
prosthetic swing time (s)	0.50	0.45	0.05	0.54	0.43	0.45	0.40	0.46	0.47	0.48

Table 27: Ramp down temporal-spatial means for ten participants without a pack.

Temporal-spatial Parameters	1	2	3	4	5	6	7	8	9	10
cycle time (s)	1.23	1.03	1.26	1.19	1.03	1.02	1.00	1.07	1.13	1.15
speed (m/s)	1.14	1.54	1.12	1.29	1.07	1.24	1.52	1.22	1.19	1.22
statures per second	0.63	0.86	0.59	0.74	0.62	0.71	0.92	0.71	0.71	0.69
stride length (m)	1.39	1.59	1.41	1.53	1.10	1.02	1.52	1.07	1.34	1.41
stride width (m)	0.15	0.12	0.15	0.20	0.11	0.12	0.14	0.17	0.15	0.19
double limb support time (s)	0.20	0.17	0.26	0.15	0.20	0.15	0.16	0.10	0.19	0.19
intact limb cycle time (s)	1.22	1.03	1.26	1.18	1.03	1.03	1.00	1.07	1.13	1.15
intact limb stance time (s)	0.72	0.62	0.78	0.70	0.63	0.61	0.59	0.60	0.67	0.70
intact limb step length (m)	0.67	0.76	0.71	0.71	0.59	0.59	0.77	0.63	0.63	0.70
intact limb step time (s)	0.61	0.50	0.62	0.60	0.51	0.49	0.49	0.53	0.56	0.57
intact limb steps per minute	98.59	119.29	97.10	100.78	118.22	121.48	121.99	113.86	108.21	104.99
intact limb stride length (m)	1.33	1.51	1.42	1.42	1.18	1.18	1.54	1.25	1.27	1.40
intact limb strides per minute	49.04	58.35	47.54	50.97	58.57	58.53	60.17	56.17	53.36	52.18
intact limb swing time (s)	0.51	0.41	0.47	0.50	0.39	0.41	0.41	0.47	0.45	0.45
prosthetic cycle time (s)	1.23	1.03	1.25	1.19	1.02	1.02	1.01	1.07	1.13	1.15
prosthetic stance time (s)	0.71	0.58	0.74	0.64	0.59	0.56	0.57	0.57	0.64	0.64
prosthetic step length (m)	0.72	0.83	0.69	0.80	0.50	0.68	0.74	0.67	0.70	0.70
prosthetic step time (s)	0.61	0.53	0.63	0.60	0.51	0.53	0.51	0.54	0.57	0.58
prosthetic steps per minute	97.88	113.68	95.81	101.14	117.29	113.06	118.06	110.60	105.44	104.04
prosthetic stride length (m)	1.44	1.66	1.39	1.61	0.99	1.36	1.48	1.34	1.39	1.41
prosthetic strides per minute	48.80	48.43	48.20	50.64	58.71	58.66	59.71	56.06	53.27	52.24
prosthetic swing time (s)	0.51	0.46	0.52	0.55	0.43	0.46	0.43	0.50	0.50	0.51

Appendix C: Kinematic Subject Data

Table 28: Level ground test variable means for prosthetic limb with a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	-2.37	-8.76	-3.24	-0.68	-6.22	-15.83	-10.47	-1.56	-11.35	-11.94
AA2	13.61	14.73	16.98	18.41	14.97	6.89	10.62	17.80	17.40	6.32
AA3	1.77	-0.32	4.64	4.00	2.41	-9.87	-2.69	3.32	-3.87	-6.16
AAV1	31.03	102.59	51.14	56.29	71.00	39.93	53.78	40.96	85.64	50.30
AAV2	45.29	74.08	59.86	50.68	57.74	106.10	61.68	78.60	108.94	52.06
AAV3	-111.79	-150.49	-100.29	-139.52	-115.96	-148.39	-126.09	-162.12	-226.08	-116.23
KA1	2.81	-21.98	0.26	-9.05	3.03	-3.06	-8.59	-4.86	-13.27	-7.83
KA2	14.35	5.39	9.86	-4.48	12.68	-1.37	8.48	2.97	-1.59	3.36
KA3	-51.97	-67.08	-63.73	-57.12	-50.91	-78.85	-56.48	-66.51	-62.0	-61.27
KAV1	59.55	149.65	62.32	27.08	49.89	25.41	91.70	43.15	93.72	66.98
KAV2	-332.35	-428.66	-386.74	-305.46	-300.35	-388.38	-382.12	-396.03	-380.05	-374.01
KAV3	365.82	415.67	381.12	259.96	311.82	420.55	338.80	395.61	390.57	359.04
HA1	-13.79	-15.93	-17.00	-12.54	-30.59	6.16	-25.92	-13.38	-12.76	-11.88
HA2	27.52	35.68	37.82	32.63	14.52	57.57	34.20	28.29	41.39	42.66
HA3	5.25	5.52	0.87	8.56	-4.03	11.64	1.50	-0.49	3.23	9.71
HA4	-5.60	-2.40	-10.92	-4.07	-11.14	-1.23	-6.03	-6.38	-8.14	-3.61
HAV1	-88.14	-164.73	-134.68	-126.93	-96.03	-117.08	-164.98	-110.41	-150.56	-132.92
HAV2	169.42	201.30	209.55	163.78	173.51	207.06	217.64	201.11	222.30	212.47
HAV3	32.86	48.28	54.70	47.05	46.23	47.24	52.34	39.83	29.62	61.15
HAV4	-67.32	-52.27	-44.65	-49.83	-27.29	-41.68	-33.0	-21.43	-68.77	-49.64

Table 29: Level ground test variable means for prosthetic limb without a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	-6.83	-9.65	-3.05	-0.39	-5.84	-15.44	-12.78	-1.17	-12.43	-11.48
AA2	6.80	12.77	12.50	16.31	13.41	5.66	6.22	15.95	15.09	4.50
AA3	-0.72	-0.25	3.13	3.53	1.80	-9.79	-4.99	3.17	-5.37	-6.20
AAV1	32.14	76.83	47.82	53.46	61.77	33.78	48.72	37.58	80.24	55.79
AAV2	36.27	62.20	50.71	48.02	52.87	97.31	55.33	71.49	103.96	38.64
AAV3	-94.52	-158.88	-73.70	-114.12	-112.86	-137.38	-110.76	-140.05	-202.88	-107.23
KA1	1.80	-12.92	5.30	-8.56	3.85	-1.57	-4.23	-0.40	-11.41	-9.68
KA2	13.69	5.01	11.09	-5.60	12.41	-0.87	6.69	5.14	-1.79	4.88
KA3	-51.07	-66.36	-62.98	-55.68	-51.38	-75.92	-57.55	-56.92	-63.54	-62.48
KAV1	65.11	98.72	40.62	21.41	42.96	23.41	60.42	33.25	62.27	89.91
KAV2	-327.53	-437.63	-395.45	-259.24	-289.93	-388.70	-349.95	-356.56	-380.80	-363.67
KAV3	363.99	421.87	388.99	267.11	301.64	446.33	360.23	378.44	401.82	378.77
HA1	-30.28	-16.15	-13.63	-16.34	-20.71	1.75	-18.17	-21.87	-22.61	-25.79
HA2	10.82	32.44	29.87	23.57	20.60	49.32	27.61	18.53	18.26	26.18
HA3	4.18	4.15	-0.22	8.06	-3.33	12.02	0.30	0.16	0.46	3.58
HA4	-3.19	-4.43	-10.76	-2.19	-12.55	0.87	-9.45	-6.43	-13.01	-9.00
HAV1	-88.12	-149.64	-100.50	-98.25	-102.87	-122.96	-120.72	-101.86	-113.25	-134.38
HAV2	157.82	210.85	173.91	127.27	149.04	182.91	181.28	177.84	187.14	219.33
HAV3	23.86	50.83	61.97	47.77	49.36	45.46	55.82	57.32	44.37	69.70
HAV4	-62.83	-62.01	-60.44	-44.82	-31.79	-49.45	-49.50	-26.82	-97.52	-56.97

Table 30: Level ground test variable means for intact limb with a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	-5.41	-11.21	-1.26	-3.80	-5.19	-15.32	-6.15	-1.90	-5.12	-13.07
AA2	7.51	5.08	16.27	14.46	19.18	-0.05	11.54	9.82	10.06	8.85
AA3	-14.95	-24.68	-16.14	-13.64	-6.71	-39.10	-19.97	-18.00	-19.43	-21.51
AAV1	64.48	116.00	50.23	92.22	58.28	75.05	93.11	63.84	76.52	127.40
AAV2	34.76	39.99	56.64	59.82	69.91	47.93	34.20	26.89	49.83	50.55
AAV3	-205.25	-304.70	-297.93	-298.69	-291.64	-404.71	-331.36	-286.58	-388.24	-309.23
KA1	-15.79	-30.12	-30.14	-21.67	-1.38	-19.69	-23.37	-11.21	-23.71	-10.02
KA2	3.63	1.43	-12.93	3.03	11.48	2.05	-1.80	6.69	2.82	8.15
KA3	-62.26	-60.52	-71.96	-61.55	-42.97	-59.23	-68.86	-46.29	-57.03	-33.89
KAV1	86.33	141.43	82.35	111.05	50.37	116.82	89.42	85.53	129.76	97.58
KAV2	-346.82	-386.32	-300.77	-381.47	-269.47	-316.70	-393.28	-332.31	-387.17	-249.94
KAV3	430.50	333.00	350.48	325.90	271.86	413.55	468.96	393.18	397.93	245.77
HA1	-9.01	-16.59	0.67	-14.17	-37.50	1.72	-13.35	-22.11	-8.06	-15.12
HA2	37.44	41.33	44.41	34.65	12.86	48.80	30.20	18.65	33.44	22.58
HA3	2.17	0.24	8.17	11.66	11.87	8.46	13.02	4.12	10.12	14.71
HA4	-7.92	-8.56	0.57	4.37	3.74	2.74	-2.54	-2.47	-3.38	3.58
HAV1	-65.47	-114.04	-73.58	-129.23	-108.19	-138.72	-100.07	-100.44	-102.26	-83.52
HAV2	136.95	177.22	121.16	196.47	186.33	205.50	188.08	189.51	194.31	126.09
HAV3	41.14	48.93	34.91	46.12	35.52	32.78	39.10	29.56	65.26	80.02
HAV4	-33.20	-38.71	-34.45	-68.67	-51.86	-48.13	-50.01	-54.31	-49.44	-48.97

Table 31: Level ground test variable means for intact limb without a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	-8.01	-14.50	-5.05	-4.99	-7.47	-18.00	-7.00	-4.19	-10.80	-11.70
AA2	9.33	5.04	15.23	16.53	19.64	0.56	12.60	8.87	12.66	6.47
AA3	-13.07	-24.50	-8.84	-11.15	-6.53	-36.88	-15.74	-17.45	-16.39	-21.87
AAV1	81.48	109.35	43.43	71.51	59.79	77.08	97.40	58.63	77.50	109.24
AAV2	42.14	40.46	65.51	65.99	66.37	53.50	44.88	30.41	71.71	35.36
AAV3	-214.11	-321.34	-261.51	-282.65	-287.11	-411.59	-287.96	-265.94	-371.17	-287.74
KA1	-13.62	-22.39	-17.10	-17.40	0.99	-16.04	-20.98	-6.34	-17.65	-10.14
KA2	3.14	-0.07	-10.28	-1.67	8.08	-1.22	-5.56	6.62	-3.98	7.34
KA3	-61.50	-62.45	-71.90	-64.21	-45.50	-61.86	-72.79	-45.86	-60.62	-39.64
KAV1	83.57	123.11	49.00	75.93	35.32	76.64	78.30	64.02	62.88	83.03
KAV2	-333.75	-377.48	-334.94	-354.83	-249.86	-342.14	-375.64	-307.46	-357.50	-270.78
KAV3	448.53	415.09	435.51	335.82	286.39	437.63	473.54	382.23	462.24	290.94
HA1	-24.86	-15.73	-1.13	-15.31	-23.55	-0.99	-10.92	-27.08	-21.94	-29.22
HA2	18.60	35.22	40.99	23.28	17.20	38.51	30.09	10.89	21.53	12.60
HA3	0.72	-0.61	9.31	10.58	10.78	7.44	9.60	5.35	5.40	6.78
HA4	-6.46	-8.19	1.54	4.61	2.27	-0.06	-6.45	-1.00	-5.62	-1.61
HAV1	-71.38	-135.81	-91.13	-112.81	-94.13	-112.29	-101.20	-99.79	-109.85	-92.07
HAV2	112.93	209.98	119.56	159.59	152.13	196.65	163.47	172.79	187.94	144.39
HAV3	29.88	51.98	50.46	45.35	44.81	41.01	58.95	30.93	60.24	71.71
HAV4	-34.36	-52.43	-65.53	-51.25	-43.07	-61.01	-56.64	-54.55	-62.47	-55.54

Table 32: Level ground test variable means for pelvis and trunk with a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
PR1	4.46	4.03	10.32	5.92	4.53	6.25	12.85	4.81	11.58	10.65
PR2	2.69	6.83	7.48	6.30	5.39	5.65	9.61	3.58	6.07	6.12
PR3	4.70	9.09	18.94	6.39	5.44	6.35	3.87	6.66	7.97	7.06
TR1	3.11	3.63	10.05	7.82	4.20	7.29	14.46	4.83	11.23	4.96
TR2	4.11	9.85	8.77	5.54	7.64	3.96	13.41	4.99	12.94	10.19
TR3	6.30	13.98	16.56	15.43	10.27	11.14	8.10	11.25	6.70	8.90
PAV1	-5.80	-4.09	-15.04	-18.65	-28.94	-15.63	-31.82	-14.83	-30.80	-21.61
PAV2	10.90	9.78	37.90	31.16	15.82	24.77	47.03	29.40	36.35	29.23
PAV3	-10.51	-23.55	-23.56	-16.50	-14.41	-19.18	-28.17	-17.25	-22.13	-22.18
PAV4	2.56	17.13	8.07	17.25	11.86	21.54	33.62	20.44	18.25	26.72
PAV5	-13.95	-45.58	-55.85	-27.54	-10.51	-20.51	-11.39	-28.85	-25.71	-12.55
PAV6	13.88	27.38	8.17	25.60	30.73	19.89	24.11	19.49	5.09	14.98
TAV1	-14.39	-18.51	-51.77	-43.09	-18.58	-38.28	-50.62	-28.01	-37.70	-18.28
TAV2	12.14	24.79	35.37	37.61	12.93	31.18	44.13	26.82	29.34	17.20
TAV3	-17.01	-47.77	-37.52	-37.75	-25.88	-32.38	-41.16	-31.51	-41.63	-39.17
TAV4	14.53	51.22	32.82	26.85	20.15	32.39	44.36	25.69	54.43	49.19
TAV5	-16.43	-47.20	-45.59	-35.47	-22.22	-25.86	-17.20	-34.83	-22.94	-23.40
TAV6	23.77	60.46	71.26	46.91	36.59	24.26	27.73	43.64	23.69	31.24

Table 33: Level ground test variable means for pelvis and trunk without a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
PR1	3.48	5.55	4.17	6.36	4.49	7.15	4.65	4.79	5.26	8.29
PR2	4.08	5.97	7.42	4.89	3.75	6.14	12.57	3.62	6.71	7.58
PR3	4.14	10.52	25.26	10.86	8.24	13.25	12.60	8.48	13.60	11.49
TR1	3.71	6.35	7.19	6.20	7.74	7.20	-6.66	5.11	8.35	6.97
TR2	3.71	8.61	9.47	4.40	6.83	6.19	-18.96	3.81	10.84	8.55
TR3	13.64	19.32	35.62	20.42	14.89	21.82	-25.63	16.42	19.28	21.74
PAV1	-3.73	-14.06	-0.65	-8.48	-11.75	-16.45	-11.97	-10.67	-17.17	-19.94
PAV2	11.39	22.46	12.94	27.50	36.07	24.33	21.84	26.84	30.58	40.94
PAV3	-13.54	-32.85	-32.98	-16.06	-15.27	-31.98	-35.69	-19.64	-24.90	-26.05
PAV4	6.42	21.29	23.88	14.74	5.05	28.95	47.27	23.32	30.10	19.09
PAV5	-18.20	-35.41	-74.36	-23.15	-15.88	-40.45	-24.40	-25.86	-33.05	-34.71
PAV6	21.98	31.11	59.55	40.44	44.80	48.50	47.05	29.48	32.32	47.38
TAV1	-16.37	-43.18	-38.68	-35.09	-43.19	-31.15	-25.28	-27.46	-42.52	-43.71
TAV2	12.78	29.92	36.07	24.43	29.20	29.23	29.25	34.23	46.00	32.03
TAV3	-16.67	-54.20	-61.73	-24.52	-31.60	-57.08	-71.07	-28.91	-63.83	-43.37
TAV4	13.86	50.75	58.56	20.13	26.79	60.95	70.84	20.43	35.67	39.87
TAV5	-37.61	-60.65	-71.86	-56.62	-44.82	-63.77	-65.92	-41.83	-56.68	-67.46
TAV6	42.42	69.55	101.85	50.10	34.16	61.25	66.75	56.36	57.55	55.98

Table 34: Uneven ground test variable means for prosthetic limb with a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	-0.80	-4.40	-4.08	1.74	-4.41	-14.32	-7.29	0.10	-9.18	-9.82
AA2	16.08	15.04	13.26	17.11	15.92	6.13	9.04	18.47	17.31	6.53
AA3	4.31	-0.56	1.42	4.05	2.67	-8.39	-3.42	3.15	-3.37	-5.92
AAV1	31.22	63.98	38.20	41.67	71.83	37.52	33.97	29.08	80.24	42.45
AAV2	41.98	67.11	63.31	47.56	58.18	73.39	53.53	84.73	110.23	39.80
AAV3	-129.82	-162.87	-105.80	-120.77	-151.64	-138.99	-120.52	-182.82	-244.17	-112.50
KA1	6.08	-19.55	-1.34	-11.21	-0.01	-3.33	-5.66	-7.16	-12.20	-4.99
KA2	14.30	4.29	16.17	-7.15	12.40	0.83	9.18	5.12	0.31	3.21
KA3	-71.05	-81.59	-74.42	-71.21	-71.81	-91.07	-65.11	-79.79	-80.84	-79.37
KAV1	50.63	148.54	113.51	42.79	63.50	38.64	89.45	69.31	117.51	51.03
KAV2	-400.99	-496.20	-444.16	-334.49	-388.60	-433.76	-414.83	-491.46	-510.49	-441.56
KAV3	446.30	455.38	444.83	291.90	392.37	467.03	355.41	431.99	467.38	390.56
HA1	-20.63	-17.04	-16.88	-7.32	-13.99	11.40	-26.86	-15.08	-7.95	-13.77
HA2	36.85	44.0	44.55	36.35	39.86	63.95	39.19	37.44	54.70	47.12
HA3	5.46	4.95	3.63	4.00	-1.53	10.19	1.36	-1.61	5.06	12.52
HA4	-4.53	-1.95	-10.52	-5.52	-14.24	-2.82	-3.81	-7.57	-2.70	-2.62
HAV1	-100.79	-172.83	-154.27	-122.43	-108.46	-111.41	-164.66	-143.06	-158.46	-117.73
HAV2	197.98	268.52	215.37	207.24	219.72	194.48	244.69	257.39	286.55	241.16
HAV3	22.18	49.67	54.22	38.85	56.88	46.45	25.74	35.84	36.46	63.99
HAV4	-64.47	-45.18	-53.35	-40.08	-53.05	-40.77	-34.16	-31.65	-44.26	-51.31

Table 35: Uneven ground test variable means for prosthetic limb without a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	-0.41	-6.50	-2.94	0.28	-3.34	-14.53	-7.93	0.04	-9.68	-9.37
AA2	14.69	13.24	11.26	14.99	14.75	5.24	7.48	16.08	15.87	5.18
AA3	4.11	-0.36	1.65	3.90	2.41	-8.73	-3.24	3.20	-3.55	-5.98
AAV1	27.73	61.13	31.89	41.50	54.52	38.28	36.45	25.98	55.91	35.88
AAV2	38.25	58.0	44.76	44.00	48.96	75.56	44.43	76.10	111.06	34.84
AAV3	-132.85	-161.42	-92.17	-115.03	-127.78	-137.76	-107.32	-119.82	-239.93	-104.45
KA1	5.09	-12.07	3.31	-4.71	1.63	-0.22	-0.10	-5.45	-5.43	-3.40
KA2	13.49	2.90	15.34	-3.26	12.30	1.147	6.50	6.59	0.62	4.37
KA3	-71.11	-83.30	-72.80	-67.27	-75.60	-88.92	-65.08	-77.37	-78.50	-79.15
KAV1	50.17	110.95	91.68	18.33	55.47	30.01	46.93	60.97	48.23	48.00
KAV2	-410.78	-478.52	-407.59	-325.40	-361.26	-411.75	-385.14	-451.49	-484.59	-415.70
KAV3	454.49	442.27	435.96	320.54	409.96	467.84	377.37	417.21	486.00	391.14
HA1	-31.33	-16.35	-17.15	-14.54	-21.10	2.47	-20.15	-20.08	-22.32	-25.56
HA2	26.47	37.15	36.70	26.34	32.24	53.40	28.70	33.25	30.39	33.06
HA3	6.23	2.78	-0.46	3.30	-2.37	7.82	1.67	-2.01	3.06	5.47
HA4	-4.96	-3.87	-8.94	-4.37	-11.72	-5.96	-4.86	-5.95	-8.26	-7.45
HAV1	-107.80	-146.28	-128.36	-106.22	-112.04	-123.87	-114.53	-137.63	-110.27	-130.20
HAV2	217.02	233.56	196.01	166.08	191.08	186.40	184.71	223.42	245.46	248.06
HAV3	29.18	49.08	55.47	47.04	51.18	40.23	28.50	31.26	42.36	70.04
HAV4	-69.22	-43.03	-51.11	-36.88	-33.32	-64.72	-37.62	-28.67	-83.92	-44.17

Table 36: Uneven ground test variable means for intact limb with a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	0.99	-5.01	3.53	4.99	0.83	-9.84	2.66	0.36	0.78	-4.49
AA2	7.83	3.65	15.76	13.32	18.39	-0.73	11.98	6.91	9.45	9.28
AA3	-20.76	-27.52	-22.72	-4.39	-7.59	-39.26	-19.29	-23.83	-24.24	-20.47
AAV1	48.21	81.05	32.64	52.88	64.14	56.73	67.57	67.48	74.90	75.18
AAV2	24.65	35.15	38.83	40.26	58.16	28.91	22.81	15.30	9.32	22.58
AAV3	-253.52	-313.15	-333.43	-154.38	-288.30	-315.63	-296.32	-306.75	-366.97	-265.13
KA1	-16.59	-28.33	-29.83	-22.39	-5.79	-21.55	-27.09	-12.37	-22.13	-12.10
KA2	6.09	1.39	-10.49	4.69	14.03	-3.19	-2.81	10.32	3.34	6.93
KA3	-74.03	-75.15	-79.06	-79.78	-59.63	-77.20	-78.39	-61.39	-69.21	-52.73
KAV1	99.79	178.14	112.64	122.52	85.62	104.19	122.44	115.17	147.49	94.07
KAV2	-397.19	-501.20	-360.40	-494.68	-313.19	-402.62	-449.88	-428.30	-505.18	-349.78
KAV3	445.47	398.57	359.65	360.17	301.43	466.73	406.18	466.92	448.97	267.81
HA1	-16.74	-16.79	-0.58	-16.22	-20.84	0.86	-12.87	-24.92	-9.44	-18.48
HA2	43.87	44.06	55.57	40.11	39.89	59.88	45.88	23.64	46.61	29.39
HA3	2.19	-0.04	3.92	12.26	13.68	7.96	10.74	3.13	11.34	11.23
HA4	-8.40	-9.71	-2.71	3.91	2.35	-0.06	-3.73	-3.97	-3.67	0.06
HAV1	-107.57	-163.95	-122.30	-137.97	-129.21	-144.72	-119.19	-116.45	-133.24	-97.85
HAV2	245.51	264.34	207.96	250.20	251.95	235.35	221.23	252.59	257.18	169.11
HAV3	45.82	65.07	39.58	55.40	65.93	47.78	48.67	45.97	71.42	72.59
HAV4	-29.83	-73.29	-46.82	-61.41	-104.99	-52.85	-52.66	-55.33	-56.15	-51.79

Table 37: Uneven ground test variable means for intact limb without a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	-2.52	-7.07	0.36	1.22	0.28	-11.66	0.06	0.47	-3.76	-6.76
AA2	10.47	5.18	17.11	14.96	18.97	2.15	13.72	6.65	11.16	5.77
AA3	-19.75	-30.39	-11.47	-5.97	-3.43	-36.59	-17.62	-21.06	-19.60	-21.33
AAV1	60.08	83.47	44.82	73.87	58.35	64.12	62.75	34.50	82.64	66.34
AAV2	40.24	32.30	49.58	48.59	50.72	28.86	46.17	23.96	41.45	20.39
AAV3	-277.08	-345.85	-276.55	-230.31	-237.55	-338.90	-299.41	-283.05	-394.49	-251.86
KA1	-14.49	-21.30	-18.08	-19.36	-2.22	-13.68	-18.25	-7.88	-18.74	-5.72
KA2	5.45	-0.51	-10.93	1.01	9.14	-0.49	-1.64	7.93	-0.30	10.89
KA3	-74.76	-74.66	-79.87	-83.26	-59.98	-76.23	-82.22	-60.24	-71.84	-53.04
KAV1	92.91	124.40	51.44	111.11	52.66	60.67	96.74	85.34	88.82	79.51
KAV2	-391.52	-427.42	-354.53	-443.81	-291.33	-379.79	-440.75	-386.93	-444.05	-337.30
KAV3	506.16	448.71	469.52	374.12	305.05	475.40	486.94	447.69	562.29	347.19
HA1	-27.17	-18.12	-3.99	-20.37	-24.19	-2.91	-13.79	-27.89	-21.96	-31.72
HA2	30.37	38.71	45.06	34.81	29.16	47.14	36.24	16.80	28.29	14.49
HA3	0.90	-1.69	8.16	10.69	11.81	5.08	7.17	3.98	6.81	4.97
HA4	-7.36	-9.82	-2.58	4.60	2.54	-2.04	-6.95	-2.30	-5.10	-4.03
HAV1	-116.97	-153.60	-112.49	-147.16	-107.89	-117.40	-107.03	-106.59	-113.88	-99.12
HAV2	228.48	249.71	163.10	220.18	187.21	214.23	207.08	221.87	231.25	192.92
HAV3	37.31	63.92	76.41	58.37	51.22	49.21	56.29	41.43	69.75	74.55
HAV4	-25.92	-101.35	-66.53	-61.81	-64.34	-51.52	-56.78	-48.92	-44.70	-52.63

Table 38: Uneven ground test variable means for pelvis and trunk with a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
PR1	3.51	6.25	7.99	6.99	4.10	7.93	19.11	6.49	10.58	6.43
PR2	4.29	9.79	7.95	10.94	9.71	10.76	9.76	5.94	9.11	6.96
PR3	3.74	13.20	10.06	6.85	10.47	8.63	4.69	8.53	7.64	8.87
TR1	3.93	7.02	7.74	8.64	6.32	11.50	19.75	-7.93	10.35	5.05
TR2	5.14	10.43	12.92	10.62	13.05	4.57	12.35	-7.50	15.77	8.53
TR3	7.94	16.35	14.51	0.36	17.26	17.61	8.07	-11.63	5.26	10.42
PAV1	-11.73	-9.67	-10.91	-27.04	-21.33	-9.50	-55.45	-27.24	-56.78	-11.99
PAV2	10.34	15.82	20.01	14.39	13.74	25.50	63.54	33.69	47.77	18.68
PAV3	-14.16	-27.81	-31.33	-28.42	-25.15	-17.08	-29.65	-27.12	-39.26	-20.24
PAV4	9.52	32.53	24.10	28.25	30.34	23.31	40.37	30.07	23.42	26.11
PAV5	-10.79	-59.29	-37.48	-38.11	-45.95	-45.70	-12.92	-32.34	-25.92	-9.22
PAV6	15.00	27.23	21.27	28.68	41.18	24.67	10.24	20.16	8.96	19.44
TAV1	-17.16	-33.35	-35.56	-60.68	-32.73	-44.03	-75.52	-48.31	-39.34	-26.36
TAV2	19.19	39.29	38.86	59.45	37.23	36.97	61.40	36.01	17.78	23.54
TAV3	-22.03	-63.44	-47.17	-30.61	-51.50	-45.54	-42.74	-46.50	-50.39	-30.71
TAV4	20.53	53.97	44.44	30.75	51.15	43.15	41.45	32.87	81.61	49.60
TAV5	-22.41	-56.64	-44.46	-46.46	-62.80	-44.86	-23.39	-43.68	-27.53	-23.92
TAV6	27.11	61.30	58.41	61.87	57.70	49.80	21.59	44.50	21.89	25.74

Table 39: Uneven ground test variable means for pelvis and trunk without a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
PR1	3.60	6.58	3.04	5.99	4.42	6.36	5.38	6.26	3.91	5.98
PR2	5.71	8.62	8.29	10.19	8.44	10.60	9.93	6.17	5.39	9.04
PR3	5.68	14.07	25.46	13.16	12.43	15.92	11.34	10.71	18.76	14.62
TR1	4.68	9.02	10.64	8.55	8.74	-9.54	7.44	8.96	7.93	6.54
TR2	4.48	10.38	12.46	15.01	12.81	-6.72	18.13	4.24	12.01	7.63
TR3	15.00	22.11	27.91	0.33	19.37	-22.76	24.03	17.55	22.62	25.42
PAV1	-5.06	-22.69	-8.52	-18.25	-14.34	-3.85	-8.60	-24.00	-12.75	-13.94
PAV2	7.32	23.60	16.32	12.38	20.23	23.49	14.38	21.88	27.81	29.14
PAV3	-11.35	-32.06	-39.09	-28.15	-21.93	-28.04	-35.61	-26.45	-31.84	-24.78
PAV4	12.84	22.53	36.89	32.08	21.56	35.06	46.13	23.33	37.74	28.14
PAV5	-31.61	-44.28	-50.19	-44.23	-37.73	-45.16	-40.98	-39.98	-59.96	-36.04
PAV6	28.26	30.17	74.91	39.70	43.42	40.63	36.64	38.91	47.24	39.91
TAV1	-22.88	-44.34	-40.78	-59.17	-40.18	-44.00	-26.89	-54.11	-37.93	-32.68
TAV2	21.88	50.44	44.46	46.16	25.64	43.01	40.58	36.23	36.97	27.72
TAV3	-22.55	-53.51	-59.31	-40.61	-48.62	-58.30	-69.43	-26.61	-63.54	-33.04
TAV4	18.76	61.85	63.06	29.02	44.70	57.08	70.93	24.00	60.08	43.32
TAV5	-53.74	-89.96	-41.13	-69.01	-66.36	-61.40	-63.43	-60.39	-82.80	-66.22
TAV6	51.94	71.14	62.22	63.81	55.48	65.90	66.71	68.26	67.91	76.95

Table 40: Ramp down test variable means for prosthetic limb with a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	-9.20	-11.80	-8.18	-2.11	-7.71	-16.75	-12.35	-3.31	-14.35	-13.47
AA2	8.48	12.45	13.59	14.83	13.41	4.71	8.73	16.74	18.33	4.85
AA3	-0.98	-0.45	2.45	2.98	2.84	-13.06	-2.99	3.11	-8.48	-5.90
AAV1	55.34	117.02	54.11	58.07	72.58	27.30	77.45	69.33	135.86	60.03
AAV2	50.91	57.01	63.94	48.42	41.42	102.48	46.57	75.92	118.05	53.58
AAV3	-96.54	-101.49	-112.39	-119.20	-100.08	-175.37	-100.67	-142.99	-274.08	-105.12
KA1	-3.61	-21.67	6.41	-17.99	-1.14	-6.19	-4.36	-14.29	-20.40	-10.52
KA2	-3.42	-8.78	5.66	-15.69	2.94	-6.19	1.02	-14.29	-5.24	-6.27
KA3	-59.02	-74.64	-65.94	-61.82	-56.28	-81.71	-50.90	-74.10	-70.10	-68.34
KAV1	-12.88	94.95	54.62	22.73	23.36	-8.33	36.22	-20.58	85.19	35.50
KAV2	-249.87	-407.02	-427.03	-316.68	-299.39	-450.68	-282.86	-363.42	-478.59	-411.80
KAV3	381.73	479.80	361.15	308.49	295.28	429.20	319.09	398.46	433.01	329.60
HA1	-10.58	-10.37	-14.30	-7.21	-24.65	13.35	-15.64	-5.70	-19.33	-11.31
HA2	21.28	28.03	26.69	19.87	8.91	45.84	21.99	25.77	27.94	25.75
HA3	7.71	10.42	2.16	5.57	-5.60	6.78	1.35	-2.84	5.45	8.31
HA4	-2.46	-1.62	-9.46	-1.03	-15.47	-4.08	-9.22	-7.51	-4.68	-1.15
HAV1	-56.97	-134.89	-96.88	-74.50	-75.01	-96.68	-112.00	-86.44	-155.10	-102.39
HAV2	139.44	208.60	161.91	136.32	150.49	163.87	162.14	155.01	232.74	154.16
HAV3	31.82	54.17	57.56	54.92	66.26	54.91	47.43	28.36	36.63	45.06
HAV4	-53.35	-107.72	-83.76	-30.22	-26.30	-61.77	-32.43	-27.18	-81.59	-37.22

Table 41: Ramp down test variable means for prosthetic limb without a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	-8.81	-11.52	-7.21	-2.24	-7.32	-16.44	-11.73	-2.63	-13.36	-12.20
AA2	7.89	10.98	10.03	13.38	11.69	3.36	6.90	15.01	15.40	2.46
AA3	-0.90	-2.04	2.17	1.74	2.69	-10.52	-3.01	3.50	-7.99	-6.03
AAV1	63.12	122.88	61.83	68.12	79.13	45.14	77.12	74.73	119.88	61.71
AAV2	47.69	60.51	67.74	45.23	37.53	92.96	43.37	70.77	83.05	53.68
AAV3	-97.96	-132.69	-81.77	-120.85	-94.16	-146.47	-88.26	-114.86	-220.19	-75.47
KA1	-8.36	-23.73	-5.79	-17.06	-3.47	-13.7	-10.38	-20.95	-21.96	-12.02
KA2	-8.25	-9.11	-0.02	-15.09	-0.29	-13.71	-9.28	-20.95	-10.43	-10.14
KA3	-61.17	-76.27	-71.81	-61.23	-59.80	-82.44	-59.91	-73.76	-72.78	-67.37
KAV1	-12.09	98.02	40.40	16.05	24.25	-12.34	15.22	-34.49	67.18	19.14
KAV2	-197.27	-385.69	-393.06	-319.32	-263.15	-364.94	-259.80	-278.38	-422.33	-331.41
KAV3	364.60	462.66	383.64	334.26	293.38	407.08	337.42	400.51	441.55	318.77
HA1	-20.85	-8.56	-7.14	-11.52	-10.83	19.65	-12.59	-4.31	-25.85	-16.12
HA2	7.83	27.24	21.40	12.88	17.52	44.76	15.11	19.92	11.88	14.52
HA3	6.79	7.53	2.64	4.72	-3.80	6.52	3.93	-3.07	3.92	2.34
HA4	-0.98	-3.11	-10.78	-3.53	-14.70	-5.74	-7.39	-6.91	-12.78	-6.49
HAV1	-59.23	-159.20	-100.34	-72.36	-83.47	-96.15	-88.12	-78.66	-113.48	-83.09
HAV2	130.25	199.84	124.40	122.18	125.75	106.04	121.06	130.65	194.47	123.15
HAV3	32.81	58.73	73.25	75.34	79.58	48.76	49.00	18.15	59.16	46.37
HAV4	-38.86	-93.14	-86.94	-35.67	-36.23	-54.02	-42.68	-17.82	-136.03	-40.43

Table 42: Ramp down test variable means for intact limb with a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	-10.51	-17.95	-11.34	-10.02	-12.23	-19.26	-9.04	-5.18	-13.87	-16.75
AA2	14.00	15.00	24.48	18.88	26.18	7.01	17.72	19.49	14.04	11.62
AA3	-8.94	-17.71	-6.23	-1.62	3.82	-24.14	-7.20	-10.68	-15.85	-15.81
AAV1	74.59	158.55	124.60	80.21	91.93	75.02	91.15	103.23	97.76	115.71
AAV2	62.83	74.00	83.41	84.79	83.59	82.93	74.25	66.83	83.90	85.10
AAV3	-233.66	-396.66	-362.51	-209.64	-245.65	-384.52	-269.63	-328.66	-426.52	-275.58
KA1	-18.56	-27.62	-31.10	-18.18	-0.89	-19.04	-21.67	-17.79	-22.16	-14.24
KA2	-15.36	-20.51	-25.88	-14.08	-1.25	-18.26	-14.80	-16.98	-11.50	-10.37
KA3	-67.09	-71.03	-73.65	-66.16	-48.43	-67.46	-76.69	-53.77	-66.50	-44.48
KAV1	29.50	62.07	53.73	33.40	2.21	10.17	51.82	17.39	82.26	39.06
KAV2	-290.20	-401.71	-257.24	-323.52	-203.01	-252.20	-392.04	-266.11	-390.49	-189.02
KAV3	448.13	517.43	373.94	404.61	269.76	423.67	460.15	424.68	531.73	300.10
HA1	-7.07	-10.50	-0.74	-7.40	-27.72	10.02	-4.87	-17.66	-10.49	-14.31
HA2	27.89	29.78	35.22	23.51	6.70	38.38	33.37	10.91	28.30	15.73
HA3	1.99	-1.20	5.65	13.57	13.58	12.99	10.21	4.64	8.88	13.22
HA4	-4.09	-11.02	-5.54	5.60	4.26	-3.38	0.08	-0.77	-3.18	-1.94
HAV1	-85.53	-122.40	-103.05	-103.00	-76.65	-83.71	-90.96	-72.05	-110.94	-83.23
HAV2	151.90	201.18	143.58	174.51	153.20	148.51	183.60	162.97	192.29	123.50
HAV3	45.14	94.54	85.57	46.14	30.40	68.13	53.38	30.95	72.32	54.31
HAV4	-36.76	-57.02	-66.63	-65.53	-39.54	-71.75	-50.57	-45.30	-47.05	-40.27

Table 43: Ramp down test variable means for intact limb without a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	-12.08	-16.23	-5.18	-9.43	-10.89	-20.68	-8.24	-3.73	-14.94	-13.55
AA2	15.31	14.15	26.86	18.09	24.98	5.14	17.10	16.95	15.84	11.43
AA3	-8.22	-17.78	-1.10	-2.83	5.55	-27.71	-6.88	-11.87	-11.11	-16.51
AAV1	93.25	146.75	97.19	78.50	99.73	88.24	106.48	73.31	101.89	111.24
AAV2	76.80	60.54	105.22	110.59	85.49	91.31	74.72	67.65	90.49	79.73
AAV3	-244.61	-348.90	-320.30	-237.84	-225.84	-387.73	-260.09	-303.92	-363.04	-288.00
KA1	-18.92	-30.69	-36.35	-17.46	-3.68	-20.39	-28.18	-16.47	-20.85	-17.60
KA2	-16.71	-21.48	-28.56	-11.45	-2.79	-17.71	-21.79	-15.07	-16.99	-12.38
KA3	-69.91	-71.81	-80.27	-70.77	-51.96	-71.11	-80.15	-55.85	-68.29	-45.23
KAV1	28.69	60.33	66.89	47.05	14.18	30.20	42.07	23.10	33.68	60.17
KAV2	-276.93	-329.20	-308.94	-332.14	-235.57	-261.47	-309.38	-297.09	-330.82	-189.18
KAV3	458.85	519.87	436.68	441.91	309.48	420.02	430.13	419.62	503.27	287.50
HA1	-18.74	-10.01	-3.94	-10.12	-16.14	11.31	-10.08	-21.79	-23.14	-28.28
HA2	13.47	28.41	30.49	17.02	14.34	35.74	25.36	4.78	15.62	-0.52
HA3	2.95	-0.14	10.76	13.53	13.21	10.51	6.27	4.22	8.05	6.09
HA4	-3.87	-10.98	-2.82	5.63	3.51	-7.66	-4.36	-2.32	-4.59	-3.74
HAV1	-92.09	-107.38	-146.08	-96.87	-66.48	-94.34	-102.64	-70.67	-102.63	-81.97
HAV2	146.54	185.22	173.69	147.96	136.92	146.73	154.25	152.36	194.47	114.85
HAV3	56.08	63.19	130.56	43.17	54.49	62.10	42.53	30.81	75.82	45.87
HAV4	-26.39	-46.91	-79.08	-70.49	-59.93	-83.40	-71.57	-56.03	-58.91	-34.23

Table 44: Ramp down test variable means for pelvis and trunk with a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
PR1	5.55	8.21	8.35	8.39	5.93	7.21	5.37	7.10	6.69	6.64
PR2	5.38	7.07	8.20	5.66	6.36	10.50	3.63	5.24	5.49	9.78
PR3	4.49	7.54	5.70	4.47	5.08	6.02	3.90	3.18	9.09	10.70
TR1	6.66	7.68	7.46	8.39	6.87	5.75	4.22	5.57	7.48	7.32
TR2	3.75	6.60	7.29	7.47	4.08	11.45	9.12	5.64	6.86	5.04
TR3	4.56	9.67	10.99	5.89	4.58	5.81	6.68	5.11	9.71	10.24
PAV1	-23.16	-41.56	-24.88	-31.54	-14.37	-30.96	-31.57	-28.77	-21.41	-22.77
PAV2	32.84	63.30	49.02	62.44	26.91	55.45	29.12	37.23	39.65	40.15
PAV3	-19.73	-44.10	-40.51	-19.39	-23.38	-33.28	-22.61	-18.64	-21.38	-43.35
PAV4	17.30	48.92	32.16	31.67	24.88	50.35	23.35	31.87	36.25	26.16
PAV5	-8.96	-32.86	-27.45	-23.89	-5.10	-18.97	-10.32	-12.34	-26.04	-12.74
PAV6	14.12	15.15	25.21	19.90	15.33	20.72	19.32	12.84	19.10	24.98
TAV1	-24.05	-60.28	-30.55	-48.11	-35.47	-41.64	-26.20	-35.91	-41.12	-34.14
TAV2	27.59	35.09	32.22	40.41	23.73	32.90	26.40	39.22	22.00	26.64
TAV3	-16.37	-54.59	-30.98	-24.48	-17.20	-42.16	-39.41	-28.02	-39.47	-17.25
TAV4	20.43	44.32	39.69	18.86	18.67	42.28	39.54	31.36	34.33	18.01
TAV5	-12.91	-32.68	-35.09	-38.73	-16.49	-32.01	-21.00	-24.08	-35.71	-37.86
TAV6	13.22	40.65	45.46	42.14	17.81	38.75	21.08	21.37	32.54	35.92

Table 45: Ramp down test variable means for pelvis and trunk without a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
PR1	4.95	10.58	11.44	8.19	4.47	7.66	7.88	7.34	8.34	6.85
PR2	6.05	7.11	8.57	6.96	7.87	9.92	5.62	5.00	9.57	10.11
PR3	6.64	12.77	29.04	10.04	9.01	14.76	8.79	7.04	21.38	9.64
TR1	6.77	12.69	14.76	8.80	6.54	9.51	9.49	7.05	11.33	6.34
TR2	5.60	10.52	16.46	6.42	7.61	20.30	9.74	7.57	11.89	12.71
TR3	11.36	16.90	25.78	13.96	9.19	14.55	16.97	8.67	24.46	11.47
PAV1	-19.95	-56.13	-45.15	-41.62	-18.28	-47.89	-33.69	-27.62	-39.17	-21.80
PAV2	26.52	73.67	66.13	58.14	29.25	52.83	49.41	34.66	63.79	42.03
PAV3	-22.17	-43.11	-69.11	-31.92	-31.99	-42.27	-39.11	-15.94	-29.42	-45.27
PAV4	16.93	46.89	44.60	40.17	32.33	57.10	36.08	25.66	55.31	27.91
PAV5	-9.40	-58.23	-96.17	-39.93	-14.67	-46.11	-18.71	-21.95	-76.73	-38.94
PAV6	20.11	33.38	89.58	41.52	37.47	33.93	28.15	28.73	60.75	32.72
TAV1	-31.65	-79.59	-68.95	-48.90	-44.68	-58.02	-49.70	-45.32	-67.95	-40.14
TAV2	31.36	64.23	83.07	46.81	29.17	67.13	36.43	51.81	58.39	32.72
TAV3	-18.68	-58.17	-66.22	-39.47	-31.29	-63.58	-61.05	-30.32	-85.75	-44.77
TAV4	27.90	49.71	93.94	40.03	35.91	55.09	51.86	29.58	54.81	37.91
TAV5	-35.31	-61.15	-71.80	-50.61	-34.73	-70.29	-54.68	-33.37	-78.08	-38.82
TAV6	29.51	66.09	130.08	44.48	27.63	69.97	52.39	39.99	79.25	47.44

Table 46: Ramp up test variable means for prosthetic limb with a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	-4.62	0.62	-2.08	-0.26	-1.39	-12.53	-6.66	1.26	-9.18	-7.31
AA2	9.92	17.22	15.33	17.43	16.61	6.69	10.92	20.23	20.25	7.67
AA3	-0.52	0.30	2.65	2.93	2.64	-9.47	-2.98	3.52	-7.07	-5.62
AAV1	40.08	121.02	32.63	53.39	47.62	28.81	40.55	68.53	99.78	61.78
AAV2	38.38	59.45	53.12	50.45	40.97	85.06	57.28	57.62	107.98	54.24
AAV3	-107.91	-162.75	-94.77	-120.39	-124.92	-142.33	-120.09	-168.16	-248.30	-107.83
KA1	-9.43	-38.23	-6.92	-7.22	2.22	-10.48	-3.74	-22.93	-9.96	-16.53
KA2	17.42	-17.14	19.73	-0.51	18.81	5.26	15.70	-2.62	5.09	10.40
KA3	-61.23	-70.16	-58.26	-52.52	-50.93	-76.86	-50.33	-67.68	-65.71	-60.49
KAV1	134.19	93.58	132.94	39.39	66.71	119.79	123.74	92.73	140.67	190.49
KAV2	-345.61	-373.32	-359.53	-258.11	-290.21	-410.74	-341.94	-387.74	-431.90	-352.94
KAV3	309.34	254.26	276.87	251.17	260.92	346.86	239.44	287.95	358.99	249.55
HA1	-15.32	-6.52	-18.86	-9.10	-16.93	6.14	-14.79	-13.42	-7.46	-15.83
HA2	46.17	50.54	48.77	33.67	31.16	64.03	42.70	45.51	50.93	46.99
HA3	5.74	10.29	7.29	6.47	-2.68	9.54	3.62	-0.49	7.12	14.07
HA4	-6.22	-2.69	-7.57	-6.18	-18.44	-6.22	-9.30	-10.09	-4.53	-2.65
HAV1	-143.40	-135.37	-153.21	-9.10	-106.54	-141.30	-160.13	-144.17	-169.86	-169.24
HAV2	202.44	259.48	198.68	33.67	177.31	206.83	220.34	240.88	253.54	215.59
HAV3	23.23	60.88	37.00	6.47	53.16	94.51	42.72	42.64	39.55	52.86
HAV4	-59.83	-52.82	-57.40	-6.18	-36.00	-41.02	-22.00	-32.90	-48.18	-69.73

Table 47: Ramp up test variable means for prosthetic limb without a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	-5.15	-3.30	-2.58	-0.91	-3.41	-13.60	-8.99	0.26	-10.87	-9.25
AA2	8.42	15.38	12.15	15.42	15.22	6.56	8.51	18.12	17.92	5.45
AA3	-0.80	0.14	2.37	2.61	2.36	-9.34	-3.79	3.29	-3.53	-5.83
AAV1	31.39	88.16	24.60	57.41	46.72	33.67	49.14	37.09	65.27	50.99
AAV2	37.67	75.33	47.22	49.17	45.84	90.78	58.68	75.66	108.98	55.35
AAV3	-97.99	-162.74	-82.92	-120.05	-121.22	-144.62	-99.18	-160.33	-241.12	-98.26
KA1	-5.84	-27.79	0.10	-0.90	6.70	-1.19	1.70	-17.88	-9.81	-7.28
KA2	16.88	7.89	19.77	1.24	18.53	4.09	14.26	7.78	3.25	9.44
KA3	-57.19	-71.04	-57.68	-49.92	-53.55	-74.14	-53.49	-66.67	-63.14	-60.84
KAV1	95.54	237.22	112.59	21.72	50.35	61.29	74.25	107.50	81.47	106.14
KAV2	-329.72	-452.84	-369.29	-268.55	-308.26	-372.19	-322.71	-388.85	-392.88	-339.88
KAV3	317.24	317.77	317.02	246.64	295.66	387.65	304.77	345.88	407.52	296.48
HA1	-25.82	-15.18	-18.04	-14.77	-20.45	4.66	-21.58	-19.39	-19.75	-24.44
HA2	31.73	49.42	37.60	25.16	33.49	59.68	33.63	39.22	36.34	32.59
HA3	7.99	9.15	2.74	4.00	-5.22	7.59	3.04	-2.02	2.88	9.35
HA4	-2.25	-2.20	-6.28	-5.65	-15.69	-6.77	-7.61	-8.69	-6.98	-6.03
HAV1	-131.94	-219.38	-141.61	-111.69	-118.80	-131.05	-132.30	-157.64	-153.48	-114.75
HAV2	192.78	253.60	171.97	145.16	194.69	194.00	192.07	238.03	228.53	215.69
HAV3	29.79	70.35	39.83	31.24	35.22	73.87	37.85	38.62	41.32	58.90
HAV4	-55.01	-81.31	-42.30	-41.25	-29.69	-55.91	-40.03	-29.62	-77.42	-48.80

Table 48: Ramp up test variable means for intact limb with a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	10.48	3.95	12.59	9.70	10.68	-3.62	10.10	6.98	5.84	9.69
AA2	15.58	16.67	22.78	18.79	21.96	6.17	18.37	15.76	15.58	17.38
AA3	-25.33	-28.57	-21.53	-22.32	-10.48	-43.25	-22.87	-24.17	-29.29	-27.07
AAV1	33.42	117.81	43.60	79.79	49.37	66.44	66.76	75.65	94.51	65.02
AAV2	12.16	-6.55	43.07	-11.01	43.42	15.87	11.79	-13.79	-17.79	22.08
AAV3	-308.28	-366.77	-296.58	-246.25	-266.05	-374.78	-319.81	-315.70	-423.92	-359.62
KA1	-32.86	-45.58	-48.34	-35.71	-13.30	-39.89	-41.60	-23.33	-36.32	-30.50
KA2	-2.76	-9.18	-15.22	3.48	13.13	-6.31	-4.58	8.33	-3.26	0.74
KA3	-54.77	-63.85	-63.43	-57.38	-36.36	-64.20	-67.36	-42.25	-55.16	-34.00
KAV1	111.45	145.19	138.78	140.36	86.14	126.47	147.18	134.28	144.50	138.16
KAV2	-257.50	-403.00	-296.30	-347.67	-217.12	-333.97	-370.81	-318.30	-335.22	-226.66
KAV3	229.87	269.76	146.30	219.34	136.39	298.06	251.94	307.39	214.75	81.74
HA1	-5.42	-10.40	-0.16	-16.03	-29.80	6.03	-2.79	-21.30	0.59	-18.77
HA2	54.70	55.13	56.25	40.42	40.86	60.20	53.03	30.63	50.11	40.73
HA3	3.63	3.60	9.35	13.25	15.50	9.71	12.83	3.99	12.76	13.80
HA4	-11.94	-10.81	-7.60	4.36	-0.39	-1.60	-6.46	-4.71	-5.94	4.53
HAV1	-120.32	-167.32	-132.61	-141.74	-147.46	-131.07	-131.78	-132.75	-112.90	-120.06
HAV2	197.55	242.19	183.40	191.21	212.89	190.54	210.79	204.23	210.19	157.80
HAV3	48.72	78.70	55.75	47.46	75.40	74.21	45.60	44.43	69.33	61.06
HAV4	-28.43	-59.04	-49.44	-47.25	-49.27	-62.95	-60.30	-47.86	-58.03	-39.06

Table 49: Ramp up test variable means for intact limb without a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
AA1	6.61	0.10	2.91	5.62	8.45	-9.28	5.20	4.48	0.33	2.55
AA2	12.84	9.65	22.11	12.71	20.93	2.86	15.42	11.60	11.43	12.82
AA3	-23.60	-25.86	-15.74	-22.19	-9.46	-41.87	-22.27	-24.90	-24.77	-27.02
AAV1	45.56	96.18	35.91	68.28	46.33	70.71	60.57	59.24	72.44	75.06
AAV2	-9.06	18.56	60.66	-0.86	46.60	20.44	11.61	-5.26	14.74	9.88
AAV3	-275.16	-362.09	-311.72	-251.52	-289.29	-415.40	-305.58	-295.45	-399.64	-327.74
KA1	-31.47	-37.43	-24.45	-29.07	-9.91	-23.52	-27.07	-18.26	-30.98	-24.06
KA2	4.50	0.17	-10.25	2.12	15.08	-0.73	-1.81	9.90	1.58	7.60
KA3	-60.83	-60.09	-58.51	-58.37	-36.78	-57.96	-65.27	-43.38	-55.54	-31.55
KAV1	124.47	185.13	80.10	125.52	84.38	95.50	110.51	124.37	133.88	122.55
KAV2	-316.08	-409.48	-234.54	-333.73	-217.40	-320.89	-344.66	-320.67	-357.58	-209.68
KAV3	333.96	238.08	248.50	251.90	180.22	344.70	312.31	322.67	324.39	142.37
HA1	-20.83	-15.75	-2.40	-19.95	-22.69	4.64	-11.70	-27.37	-19.17	-30.44
HA2	40.53	52.80	50.07	33.58	37.48	52.17	39.46	23.05	39.28	26.09
HA3	2.43	2.12	7.00	12.89	16.27	6.09	10.24	3.86	5.372	7.38
HA4	-9.74	-9.05	-6.59	3.94	3.60	-1.93	-7.40	-2.79	-5.93	-1.21
HAV1	-134.10	-174.50	-129.34	-145.91	-129.39	-130.50	-115.33	-130.42	-149.18	-114.99
HAV2	211.58	241.71	163.39	163.04	168.062	197.96	197.00	208.36	216.83	147.95
HAV3	54.49	59.15	54.23	60.73	77.25	26.26	58.33	47.36	71.67	74.67
HAV4	-24.84	-65.86	-62.41	-50.96	-79.46	-26.19	-59.78	-39.62	-60.95	-27.77

Table 50: Ramp up test variable means for pelvis and trunk with a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
PR1	5.33	4.88	8.46	4.79	7.65	4.82	4.91	4.92	9.47	5.87
PR2	7.27	13.40	9.59	11.50	15.12	12.83	13.69	9.68	16.84	11.33
PR3	6.33	9.51	10.59	5.80	7.62	10.18	5.74	9.28	8.37	5.00
TR1	5.21	8.70	6.48	5.08	9.54	6.06	6.81	4.97	8.55	8.35
TR2	8.18	18.35	13.96	10.50	19.44	10.30	19.02	13.40	25.69	14.96
TR3	8.46	16.66	10.70	16.19	10.14	18.01	10.15	11.16	4.82	11.04
PAV1	-9.26	-32.59	-22.18	-17.75	-19.53	-11.24	-17.46	-18.31	-33.08	-13.09
PAV2	14.45	23.47	29.70	23.06	22.43	19.55	22.65	22.50	36.55	17.95
PAV3	-16.50	-47.79	-38.78	-36.24	-53.23	-26.12	-40.56	-38.04	-53.35	-30.27
PAV4	23.23	35.61	34.24	31.99	29.08	31.16	44.85	29.97	45.12	47.51
PAV5	-25.42	-45.64	-38.67	-18.97	-24.20	-52.55	-24.15	-30.79	-34.60	-14.66
PAV6	9.61	32.75	16.93	29.74	28.32	23.33	14.04	28.72	23.66	17.40
TAV1	-13.78	-39.20	-27.94	-27.09	-36.01	-25.16	-26.79	-20.29	-25.11	-24.76
TAV2	13.44	63.20	41.26	22.56	10.00	27.46	24.94	22.35	22.96	37.61
TAV3	-28.53	-49.53	-41.15	-32.68	-50.61	-57.02	-63.73	-40.87	-72.92	-53.58
TAV4	24.21	72.43	51.86	21.59	48.19	49.84	56.07	40.89	100.33	53.34
TAV5	-17.11	-51.36	-33.56	-42.91	-30.75	-39.62	-25.18	-53.74	-24.90	-27.83
TAV6	29.81	56.45	33.48	45.64	43.26	52.87	30.02	41.98	28.41	28.86

Table 51: Ramp up test variable means for pelvis and trunk without a pack. Abbreviation definitions are in appendix E.

Test Variable	1	2	3	4	5	6	7	8	9	10
PR1	4.05	6.14	3.20	4.84	4.57	5.42	4.30	5.61	5.28	4.82
PR2	5.72	11.45	11.66	11.31	11.19	13.43	15.65	7.10	8.73	11.53
PR3	6.78	14.68	14.57	9.73	6.95	7.54	6.84	6.65	8.35	8.18
TR1	5.33	8.01	6.74	5.90	4.66	5.73	5.17	4.68	4.31	5.60
TR2	7.91	17.13	21.95	13.07	18.40	14.94	26.38	10.29	20.30	13.08
TR3	16.14	28.92	31.12	21.79	15.17	25.39	24.53	20.33	18.59	28.92
PAV1	-11.05	-42.93	-15.77	-14.19	-24.09	-8.59	-18.25	-20.37	-16.00	-15.84
PAV2	19.35	34.12	9.87	26.93	17.60	16.39	15.28	22.13	18.26	17.33
PAV3	-18.88	-51.95	-44.52	-35.53	-37.14	-47.46	-53.81	-30.15	-35.64	-28.87
PAV4	18.48	42.79	35.03	45.84	33.12	46.19	53.29	33.77	42.45	43.39
PAV5	-30.99	-66.72	-55.91	-33.94	-31.26	-30.79	-32.78	-29.96	-41.45	-32.40
PAV6	36.59	41.15	48.24	41.77	45.76	27.17	37.17	37.81	34.84	33.19
TAV1	-14.97	-33.53	-36.67	-29.10	-18.09	-20.71	-17.16	-19.59	-16.37	-17.74
TAV2	17.95	61.51	29.47	27.93	17.12	39.01	24.94	18.19	21.96	23.84
TAV3	-25.99	-58.22	-62.55	-55.31	-46.76	-71.27	-73.32	-39.56	-92.03	-38.52
TAV4	22.57	65.64	71.75	30.58	52.08	83.59	79.63	31.949	58.58	60.98
TAV5	-49.18	-95.88	-65.15	-73.86	-42.93	-65.88	-61.71	-69.55	-57.73	-71.55
TAV6	49.19	98.74	68.21	70.15	49.37	50.45	56.94	65.53	63.49	78.75

Appendix D: Kinetic Subject Data

Table 52: Level ground prosthetic limb kinetic test variable means for ten participants with a pack.

	1	2	3	4	5	6	7	8	9	10
AM1	30.60	28.03	8.06	7.53	20.91	8.45	28.63	18.51	35.72	24.44
AM2	-167.07	-177.13	-109.28	-182.66	-234.87	-143.87	-143.87	-143.94	-84.36	-160.82
AP1	-21.15	-44.00	-8.96	-4.95	-34.10	-8.53	-24.64	-9.81	-34.21	-14.63
AP2	6.91	20.38	0.20	0.19	5.41	0.24	12.32	3.49	28.88	9.81
AP3	5.02	0.49	-3.13	-16.18	-16.87	-5.68	-7.05	1.11	-7.41	-16.68
AP4	132.71	253.83	127.12	241.78	502.79	199.69	183.25	225.19	180.22	182.58
KM1	40.24	126.57	-1.97	39.96	110.76	-9.67	71.13	7.86	68.88	13.54
KM2	-63.42	-27.68	-27.28	4.06	3.74	-24.77	-10.90	-16.80	-7.64	-39.57
KP1	-22.07	-181.24	-9.20	-9.43	-84.26	-7.78	-50.64	-2.98	-118.33	-8.91
KP2	20.65	197.84	5.99	10.17	58.80	3.38	73.62	8.49	76.83	10.57
KP3	8.15	-279.08	-35.58	-122.22	-89.55	-146.87	-177.68	-152.52	-10.00	-122.27
HM1	-4.52	-48.87	-20.05	-16.72	-65.06	-58.02	-26.05	-39.38	8.84	-65.24
HM2	145.83	170.52	100.71	113.87	204.05	78.06	144.30	118.41	74.80	119.93
HP1	3.41	22.46	36.96	10.29	6.49	113.02	16.87	66.25	-5.08	120.32
HP2	-110.84	-133.94	-91.27	-89.59	-200.90	-63.44	-203.56	-88.44	-129.46	-161.87
HP3	36.92	171.00	97.62	72.53	214.23	94.82	119.57	97.91	53.11	125.67

Table 53: Level ground prosthetic limb kinetic test variable means for ten participants without a pack.

	1	2	3	4	5	6	7	8	9	10
AM1	26.75	27.75	7.33	8.27	22.86	6.52	12.76	16.52	41.90	27.31
AM2	-136.82	-140.99	-81.90	-169.65	-197.34	-121.92	-120.87	-122.68	-64.62	-130.18
AP1	-20.60	-32.50	-6.50	-21.29	-25.11	-5.73	-21.69	-7.58	-47.97	-17.27
AP2	7.82	17.26	0.98	2.26	5.37	1.12	4.05	2.64	34.91	10.86
AP3	5.20	-9.87	-1.24	-10.29	-13.58	-3.56	-13.49	12.31	2.29	-15.73
AP4	88.55	179.56	88.53	464.54	224.99	178.66	288.17	162.70	131.26	130.07
KM1	28.86	69.33	-7.69	75.16	39.70	-14.37	57.72	5.95	56.82	8.63
KM2	-58.45	-24.11	-27.62	-11.60	-21.59	-25.50	-22.13	-21.07	-5.66	-42.16
KP1	-18.57	-64.46	-5.34	-94.03	-24.16	-7.77	-66.91	-1.33	-109.98	-9.03
KP2	14.40	75.83	6.06	43.83	16.99	24.15	46.31	1.24	37.57	8.37
KP3	23.78	-187.85	-14.68	-111.71	-28.86	-118.74	-94.39	-98.72	-11.17	-88.91
HM1	-13.47	-27.14	-18.97	-45.34	-35.97	-54.95	-45.78	-35.18	12.73	-59.91
HM2	112.01	138.81	73.04	91.92	160.31	60.98	65.42	102.63	48.94	95.70
HP1	4.23	28.91	25.46	25.82	24.63	116.58	27.90	47.49	-7.92	97.77
HP2	-81.29	-81.32	-38.96	-59.35	-110.16	-32.63	-40.60	-60.39	-56.85	-110.50
HP3	27.73	113.90	50.12	91.15	150.47	66.97	57.75	69.47	45.15	77.73

Table 54: Level ground intact limb kinetic test variable means for ten participants with a pack.

	1	2	3	4	5	6	7	8	9	10
AM1	23.55	24.20	6.69	5.16	1.84	20.55	12.07	18.04	22.44	20.48
AM2	-186.75	-180.72	-114.91	-218.89	5.39	-165.98	-156.36	-178.57	-121.14	-176.81
AP1	-23.93	-32.23	-9.54	-40.47	8.68	-43.27	-14.52	-11.38	-16.19	-80.02
AP2	10.69	12.62	0.11	0.79	-1.73	5.38	3.65	5.46	23.99	-4.82
AP3	-4.96	8.36	-5.17	4.62	-9.50	-1.39	-6.16	-5.60	4.76	-4.75
AP4	277.60	471.01	299.43	637.68	-231.09	561.42	429.77	506.53	396.94	499.22
KM1	99.39	163.70	66.12	151.25	-50.34	79.25	94.69	106.96	122.46	101.25
KM2	-43.39	-31.50	0.45	-37.26	-23.50	-51.87	-19.72	-32.30	-8.81	-14.30
KP1	-68.09	-273.54	-53.68	-180.56	42.41	-105.83	-94.79	-125.42	-145.72	-148.11
KP2	84.20	264.60	69.91	191.93	-23.52	85.56	103.59	94.93	179.54	98.26
KP3	-73.35	-237.02	-118.03	-224.28	51.20	-123.54	-146.75	-138.82	-141.12	-179.72
HM1	-49.76	-111.63	-51.28	-53.00	40.18	-58.64	-52.63	-52.35	-28.94	-55.22
HM2	120.35	142.38	58.91	127.97	-14.27	79.58	103.69	153.99	111.04	181.31
HP1	7.11	21.78	42.94	8.57	3.16	25.99	29.89	7.63	7.73	35.82
HP2	-96.95	-141.82	-33.80	-101.94	27.33	-53.06	-97.70	-147.35	-112.56	-178.53
HP3	68.45	170.60	51.45	129.18	-21.56	90.76	93.13	127.86	103.19	149.71

Table 55: Level ground intact limb kinetic test variable means for ten participants without a pack.

	1	2	3	4	5	6	7	8	9	10
AM1	16.31	21.50	9.49	7.63	19.27	19.20	30.89	14.15	23.84	23.37
AM2	-155.63	-151.02	-79.60	-148.89	-197.43	-133.58	-110.82	-149.48	-86.97	-144.61
AP1	-19.14	-28.19	-13.65	-4.45	-32.93	-49.91	-25.54	-13.90	-37.59	-71.07
AP2	4.68	12.07	1.13	0.11	3.79	8.76	18.35	4.39	24.35	-3.72
AP3	-10.96	-5.94	-5.38	-9.93	-24.95	-12.53	6.27	-14.53	5.94	-11.79
AP4	225.41	372.17	183.53	166.07	398.26	418.06	124.75	404.68	285.59	381.34
KM1	50.26	96.44	21.90	37.53	61.30	49.37	42.44	62.30	62.65	66.62
KM2	-42.08	-22.54	-2.70	-7.66	3.05	-39.70	-15.66	-24.40	0.26	-23.13
KP1	-42.63	-128.19	-18.57	-12.00	-45.41	-72.22	-28.27	-73.06	-90.53	-113.30
KP2	32.61	112.58	10.63	6.60	21.40	25.88	21.37	43.54	47.60	39.39
KP3	-57.89	-153.60	-57.58	-77.77	-69.74	-54.19	-126.12	-100.00	-88.89	-158.97
HM1	-56.19	-77.81	-50.42	-18.26	-72.14	-53.42	-22.85	-44.58	-26.92	-50.15
HM2	92.43	109.85	32.41	73.94	151.23	55.95	101.64	131.38	70.92	149.31
HP1	21.72	56.48	43.23	15.36	14.81	24.60	22.33	5.58	20.57	34.59
HP2	-59.98	-89.53	-25.35	-49.90	-101.11	-41.04	-70.17	-106.97	-65.67	-152.73
HP3	54.95	113.41	39.71	50.64	170.63	40.71	73.83	83.70	76.05	123.81

Appendix E: P-Values

Table 56: P-values for level ground temporal-spatial parameters for the prosthetic, intact limb and overall values. Significant findings are bold.

Temporal-spatial Parameter	Overall	Intact	Prosthetic
cycle time (s)	0.32		
speed (m/s)	0.034		
statures per second	0.036		
stride length (m)	0.011		
stride width (m)	0.052		
double limb support time (s)	0.037		
cycle time (s)		0.36	0.30
stance time (s)		0.077	0.071
step length (m)		0.0084	0.028
step time (s)		0.77	0.24
steps per minute		0.87	0.27
stride length (m)		0.0084	0.028
strides per minute		0.46	0.33
limb swing time (s)		0.22	0.66

Table 57: P-values for uneven ground temporal-spatial parameters for the prosthetic, intact limb and overall values. Significant findings are bold.

Temporal-spatial Parameter	Overall	Intact	Prosthetic
cycle time (s)	0.12		
speed (m/s)	0.17		
statures per second	0.025		
stride length (m)	**0.0012**		
stride width (m)	0.58		
double limb support time (s)	0.042		
cycle time (s)		0.16	0.10
stance time (s)		0.56	0.93
step length (m)		**0.00087**	0.043
step time (s)		0.037	0.31
steps per minute		0.031	0.19
stride length (m)		**0.00087**	0.043
strides per minute		0.093	0.064
limb swing time (s)		**0.00037**	0.018

Table 58: P-values for ramp up temporal-spatial parameters for the prosthetic, intact limb and overall values. Significant findings are bold.

Temporal-spatial Parameter	Overall	Intact	Prosthetic
cycle time (s)	0.16		
speed (m/s)	**1.1E-05**		
statures per second	**1.2E-05**		
stride length (m)	**6.1E-05**		
stride width (m)	0.027		
double limb support time (s)	**0.00068**		
cycle time (s)		0.067	0.32
stance time (s)		0.0044	0.016
step length (m)		**0.0012**	**5.1E-05**
step time (s)		0.26	0.21
steps per minute		0.50	0.27
stride length (m)		**0.0012**	**5.1E-05**
strides per minute		0.13	0.56
limb swing time (s)		0.013	0.11

Table 59: P-values for ramp down temporal-spatial parameters for the prosthetic, intact limb and overall values. Significant findings are bold.

Temporal-spatial Parameter	Overall	Intact	Prosthetic
cycle time (s)	0.048		
speed (m/s)	0.011		
statures per second	0.011		
stride length (m)	0.86		
stride width (m)	0.76		
double limb support time (s)	**0.00020**		
cycle time (s)		0.056	0.042
stance time (s)		**0.0017**	**0.0022**
step length (m)		0.49	0.0045
step time (s)		0.038	0.035
steps per minute		0.061	0.040
stride length (m)		0.49	0.0045
strides per minute		0.063	0.90
limb swing time (s)		0.019	0.20

Table 60: P-values for level ground kinematic test variables for the prosthetic, intact limb, and pelvis and trunk. Significant findings are bold.

Test Variable	Prosthetic Limb	Intact Limb	Pelvis and Trunk
AA1	0.23	0.0035	
AA2	**0.00069**	0.42	
AA3	0.018	0.016	
AAV1	0.065	0.39	
AAV2	**3.7E-05**	0.17	
AAV3	0.0026	0.070	
KA1	0.041	0.0032	
KA2	0.80	0.029	
KA3	0.27	0.0090	
KAV1	0.082	**0.0017**	
KAV2	0.079	0.44	
KAV3	0.14	0.011	
HA1	0.23	0.23	
HA2	0.0046	0.0055	
HA3	0.084	0.057	
HA4	0.27	0.17	
HAV1	0.033	0.92	
HAV2	0.0040	0.18	
HAV3	0.086	0.34	
HAV4	0.024	0.20	
PR1			0.087
PR2			0.52
PR3			**0.0012**
TR1			0.41
TR2			0.27
TR3			0.31
PAV1			0.037
PAV2			0.72
PAV3			0.0045
PAV4			0.13
PAV5			0.066
PAV6			0.0011
TAV1			0.40
TAV2			0.63
TAV3			0.41
TAV4			0.052
TAV5			0.00010
TAV6			**0.0016**

Table 61: P-values for uneven ground kinematic test variables for the prosthetic, intact limb, and pelvis and trunk. Significant findings are bold.

Test Variable	Prosthetic Limb	Intact Limb	Pelvis and Trunk
AA1	0.57	**0.00047**	
AA2	**1.6E-06**	0.11	
AA3	0.43	0.10	
AAV1	0.048	0.84	
AAV2	0.0079	0.057	
AAV3	0.058	0.76	
KA1	**0.0020**	**0.00020**	
KA2	0.82	0.31	
KA3	0.34	0.12	
KAV1	0.010	**0.00043**	
KAV2	**0.00079**	0.0036	
KAV3	0.25	0.0078	
HA1	0.020	0.0040	
HA2	**0.00018**	**2.1E-05**	
HA3	0.032	0.074	
HA4	0.29	0.27	
HAV1	0.10	0.047	
HAV2	0.011	0.0091	
HAV3	0.44	0.65	
HAV4	0.53	0.86	
PR1			0.083
PR2			0.59
PR3			**0.0027**
TR1			0.77
TR2			0.82
TR3			0.29
PAV1			0.10
PAV2			0.26
PAV3			0.32
PAV4			0.34
PAV5			0.057
PAV6			0.0029
TAV1			0.86
TAV2			0.93
TAV3			0.31
TAV4			0.64
TAV5			**0.0015**
TAV6			0.0063

Table 62: P-values for ramp up kinematic test variables for the prosthetic, intact limb, and pelvis and trunk. Significant findings are bold.

Test Variable	Prosthetic Limb	Intact Limb	Pelvis and Trunk
AA1	**0.0012**	**6.1E-05**	
AA2	**3.6E-05**	**0.00025**	
AA3	0.78	0.028	
AAV1	0.064	0.14	
AAV2	0.13	0.21	
AAV3	0.011	0.59	
KA1	**0.00015**	0.0025	
KA2	0.28	**0.0018**	
KA3	0.41	0.38	
KAV1	0.38	0.17	
KAV2	0.95	0.68	
KAV3	**0.00035**	0.0036	
HA1	**0.00084**	0.021	
HA2	**0.0017**	**0.00014**	
HA3	0.011	0.017	
HA4	0.44	0.69	
HAV1	0.62	0.76	
HAV2	0.89	0.18	
HAV3	0.93	0.79	
HAV4	0.27	0.95	
PR1			0.098
PR2			0.20
PR3			0.21
TR1			0.056
TR2			0.51
TR3			**7.5E-05**
PAV1			0.76
PAV2			0.28
PAV3			0.94
PAV4			0.094
PAV5			0.081
PAV6			**0.00029**
TAV1			0.11
TAV2			0.88
TAV3			0.10
TAV4			0.58
TAV5			**6.8E-06**
TAV6			**0.00056**

Table 63: P-values for ramp down kinematic test variables for the prosthetic, intact limb, and pelvis and trunk. Significant findings are bold.

Test Variable	Prosthetic Limb	Intact Limb	Pelvis and Trunk
AA1	**0.0017**	0.16	
AA2	**6.0E-05**	0.63	
AA3	0.98	0.51	
AAV1	0.13	0.77	
AAV2	0.15	0.14	
AAV3	0.069	0.14	
KA1	0.0058	0.052	
KA2	**0.0013**	0.13	
KA3	0.041	**0.00049**	
KAV1	0.011	0.71	
KAV2	**0.00078**	0.54	
KAV3	0.89	0.47	
HA1	0.75	0.13	
HA2	0.027	0.017	
HA3	0.33	0.45	
HA4	0.15	0.13	
HAV1	0.36	0.59	
HAV2	**0.00026**	0.16	
HAV3	0.10	0.73	
HAV4	0.54	0.11	
PR1			0.11
PR2			0.056
PR3			0.011
TR1			0.017
TR2			0.0046
TR3			**0.00029**
PAV1			0.019
PAV2			0.12
PAV3			0.019
PAV4			0.036
PAV5			0.0055
PAV6			0.0040
TAV1			**0.0018**
TAV2			0.0050
TAV3			**0.0027**
TAV4			0.0062
TAV5			**0.00038**
TAV6			0.0049

Table 64: P-values for level ground kinetic test variables for the prosthetic and intact limb. Significant findings are bold.

Test Variable	Intact	Prosthetic
AM1	0.29	0.50
AM2	0.59	**2.0E-06**
AP1	0.61	0.97
AP2	0.33	0.96
AP3	0.046	0.40
AP4	0.35	0.49
KM1	0.065	0.15
KM2	0.046	0.14
KP1	0.040	0.58
KP2	0.0039	0.20
KP3	0.11	**0.0031**
HM1	1.00	0.84
HM2	0.64	**0.00037**
HP1	0.11	1.00
HP2	0.33	**0.0013**
HP3	0.58	0.0038

Appendix F: PEQ Correlation Coefficients for Significant and Notable Test Variables

Table 65: PEQ ambulation subscale Pearson correlation coefficients for significant and notable kinematic test variables on level ground. Correlations of moderate strength of higher are in bold.

Test Variable	Prosthetic Limb		Intact Limb		Pelvis and Trunk	
	WOP	WP	WOP	WP	WOP	WP
AA1			-0.33	-0.30		
AA2	-0.29	-0.17				
AA3						
AAV1						
AAV2	0.29	0.35				
AAV3	-0.38	**-0.42**				
KA1			0.33	0.06		
KA2						
KA3			0.19	0.09		
KAV1			0.11	0.00		
KAV2						
KAV3						
HA1						
HA2	0.06	0.04	-0.22	-0.24		
HA3						
HA4						
HAV1						
HAV2	-0.09	-0.20				
HAV3						
HAV4						
PR1						
PR2						
PR3					**-0.83**	**-0.51**
TR1						
TR2						
TR3						
PAV1						
PAV2					0.03	0.02
PAV3					**-0.71**	**-0.44**
TAV1						
TAV2						
TAV3					**-0.79**	**-0.63**

Table 66: PEQ residual limb health subscale Pearson correlation coefficients for significant and notable kinematic test variables on level ground. Correlations of moderate strength of higher are in bold.

Test Variable	Prosthetic Limb		Intact Limb		Pelvis and Trunk	
	WOP	WP	WOP	WP	WOP	WP
AA1			-0.25	-0.10		
AA2	-0.27	-0.07				
AA3						
AAV1						
AAV2	0.10	0.17				
AAV3	-0.26	-0.28				
KA1			**0.44**	0.21		
KA2						
KA3			**0.41**	0.29		
KAV1			-0.04	-0.19		
KAV2						
KAV3						
HA1						
HA2	-0.01	0.02	**-0.46**	-0.37		
HA3						
HA4						
HAV1						
HAV2	-0.02	-0.15				
HAV3						
HAV4						
PR1						
PR2						
PR3					**-0.64**	-0.30
TR1						
TR2						
TR3						
PAV1						
PAV2					0.19	0.01
PAV3					**-0.62**	-0.17
TAV1						
TAV2						
TAV3					**-0.61**	**-0.44**

Table 67: PEQ ambulation subscale Pearson correlation coefficients for significant and notable kinematic test variables on uneven ground. Correlations of moderate strength of higher are in bold.

Test Variable	Prosthetic Limb		Intact Limb		Pelvis and Trunk	
	WOP	WP	WOP	WP	WOP	WP
AA1			-0.15	-0.18		
AA2	-0.16	-0.11				
AA3						
AAV1						
AAV2	0.09	0.27				
AAV3						
KA1	-0.07	-0.06	0.27	0.10		
KA2						
KA3						
KAV1			-0.09	0.16		
KAV2	0.28	0.24	-0.24	-0.24		
KAV3			0.13	-0.03		
HA1			-0.11	-0.15		
HA2	0.22	-0.05	0.02	-0.08		
HA3						
HA4						
HAV1						
HAV2			0.25	0.36		
HAV3						
HAV4						
PR1						
PR2						
PR3					-0.39	**-0.44**
TR1						
TR2						
TR3						
PAV1						
PAV2						
PAV3						
TAV1						
TAV2						
TAV3					-0.28	0.09

Table 68: PEQ residual limb health subscale Pearson correlation coefficients for significant and notable kinematic test variables on uneven ground. Correlations of moderate strength of higher are in bold.

Test Variable	Prosthetic Limb		Intact Limb		Pelvis and Trunk	
	WOP	WP	WOP	WP	WOP	WP
AA1			0.00	-0.01		
AA2	-0.22	-0.19				
AA3						
AAV1						
AAV2	-0.02	0.12				
AAV3						
KA1	-0.13	-0.11	0.37	0.28		
KA2						
KA3						
KAV1			-0.21	0.04		
KAV2	0.35	0.39	-0.06	-0.04		
KAV3			-0.30	-0.37		
HA1			-0.21	-0.26		
HA2	0.13	-0.16	-0.19	-0.28		
HA3						
HA4						
HAV1						
HAV2			-0.06	0.03		
HAV3						
HAV4						
PR1						
PR2						
PR3					-0.22	-0.21
TR1						
TR2						
TR3						
PAV1						
PAV2						
PAV3						
TAV1						
TAV2						
TAV3					-0.18	0.19

Table 69: PEQ ambulation subscale Pearson correlation coefficients for significant and notable kinematic test variables on ramp up. Correlations of moderate strength of higher are in bold.

Test Variable	Prosthetic Limb		Intact Limb		Pelvis and Trunk	
	WOP	WP	WOP	WP	WOP	WP
AA1	**-0.49**	**-0.52**	-0.34	-0.11		
AA2	-0.17	-0.09	**-0.40**	-0.39		
AA3						
AAV1						
AAV2						
AAV3						
KA1	0.35	0.30	0.33	0.09		
KA2			**0.45**	0.39		
KA3						
KAV1						
KAV2						
KAV3	0.19	0.13	0.20	0.20		
HA1	**0.43**	0.21				
HA2	-0.12	-0.03	-0.05	-0.15		
HA3						
HA4						
HAV1						
HAV2						
HAV3						
HAV4						
PR1						
PR2						
PR3						
TR1						
TR2						
TR3					-0.01	**-0.53**
PAV1						
PAV2						
PAV3						
TAV1						
TAV2						
TAV3					-0.21	-0.38

Table 70: PEQ residual limb health subscale Pearson correlation coefficients for significant and notable kinematic test variables on ramp up. Correlations of moderate strength of higher are in bold.

Test Variable	Prosthetic Limb		Intact Limb		Pelvis and Trunk	
	WOP	WP	WOP	WP	WOP	WP
AA1	-0.36	-0.39	-0.08	0.06		
AA2	-0.09	-0.05	-0.08	-0.12		
AA3						
AAV1						
AAV2						
AAV3						
KA1	**0.43**	**0.42**	**0.43**	0.28		
KA2			**0.56**	**0.45**		
KA3						
KAV1						
KAV2						
KAV3	-0.09	-0.11	-0.18	-0.22		
HA1	0.17	0.04				
HA2	-0.35	-0.27	-0.33	-0.39		
HA3						
HA4						
HAV1						
HAV2						
HAV3						
HAV4						
PR1						
PR2						
PR3						
TR1						
TR2						
TR3					-0.05	-0.33
PAV1						
PAV2						
PAV3						
TAV1						
TAV2						
TAV3					-0.26	-0.26

Table 71: PEQ ambulation subscale Pearson correlation coefficients for significant and notable kinematic test variables on ramp down. Correlations of moderate strength of higher are in bold.

Test Variable	Prosthetic Limb		Intact Limb		Pelvis and Trunk	
	WOP	WP	WOP	WP	WOP	WP
AA1	-0.29	-0.33				
AA2	-0.16	-0.08				
AA3						
AAV1						
AAV2						
AAV3						
KA1	-0.31	-0.10				
KA2	-0.18	-0.27				
KA3			0.09	0.13		
KAV1						
KAV2	0.20	0.21				
KAV3						
HA1						
HA2						
HA3						
HA4						
HAV1						
HAV2	0.06	-0.05				
HAV3						
HAV4						
PR1						
PR2						
PR3						
TR1						
TR2					0.25	-0.16
TR3					**-0.48**	-0.29
PAV1						
PAV2						
PAV3					-0.30	**-0.48**
TAV1					-0.04	**-0.42**
TAV2					-0.09	-0.24
TAV3					-0.34	**-0.52**

Table 72: PEQ residual limb health subscale Pearson correlation coefficients for significant and notable kinematic test variables on ramp down. Correlations of moderate strength of higher are in bold.

Test Variable	Prosthetic Limb		Intact Limb		Pelvis and Trunk	
	WOP	WP	WOP	WP	WOP	WP
AA1	-0.15	-0.16				
AA2	-0.09	-0.08				
AA3						
AAV1						
AAV2						
AAV3						
KA1	-0.27	0.00				
KA2	-0.15	-0.17				
KA3			0.35	0.36		
KAV1						
KAV2	0.10	0.08				
KAV3						
HA1						
HA2						
HA3						
HA4						
HAV1						
HAV2	-0.02	-0.15				
HAV3						
HAV4						
PR1						
PR2						
PR3						
TR1						
TR2					0.14	-0.14
TR3					-0.24	-0.26
PAV1						
PAV2						
PAV3					-0.16	-0.32
TAV1					-0.05	**-0.44**
TAV2					-0.29	-0.18
TAV3					-0.09	**-0.44**

Table 73: PEQ ambulation subscale Pearson correlation coefficients for significant and notable kinetic test variables on level ground. Correlations of moderate strength of higher are in bold.

Test Variable	Prosthetic Limb		Intact Limb	
	WOP	WP	WOP	WP
AM1				
AM2	-0.22	-0.30		
AP1				
AP2				
AP3				
AP4				
KM1				
KM2				
KP1				
KP2			-0.02	-0.14
KP3	-0.07	-0.09		
HM1				
HM2	0.03	-0.13		
HP1				
HP2	-0.34	-0.04		
HP3	0.01	0.16		

Table 74: PEQ residual limb health subscale Pearson correlation coefficients for significant and notable kinetic test variables on level ground. Correlations of moderate strength of higher are in bold.

Test Variable	Prosthetic Limb		Intact Limb	
	WOP	WP	WOP	WP
AM1				
AM2	-0.26	-0.34		
AP1				
AP2				
AP3				
AP4				
KM1				
KM2				
KP1				
KP2			-0.10	-0.28
KP3	-0.08	-0.12		
HM1				
HM2	0.04	-0.10		
HP1				
HP2	**-0.48**	-0.21		
HP3	0.19	0.34		

Appendix G: Median Participant Representative Curves for Kinematics and Kinetics

To select a representative subject, all subjects were ranked for each test variable (i.e., lowest score to highest score). These ranks were summed for each participant. The median of these summed ranks was used to select the representative participant.

Figure 17: Mean and standard deviation curves from the median participant for the pelvis joint angles on level ground. WP condition is solid lines and WOP condition is broken lines.

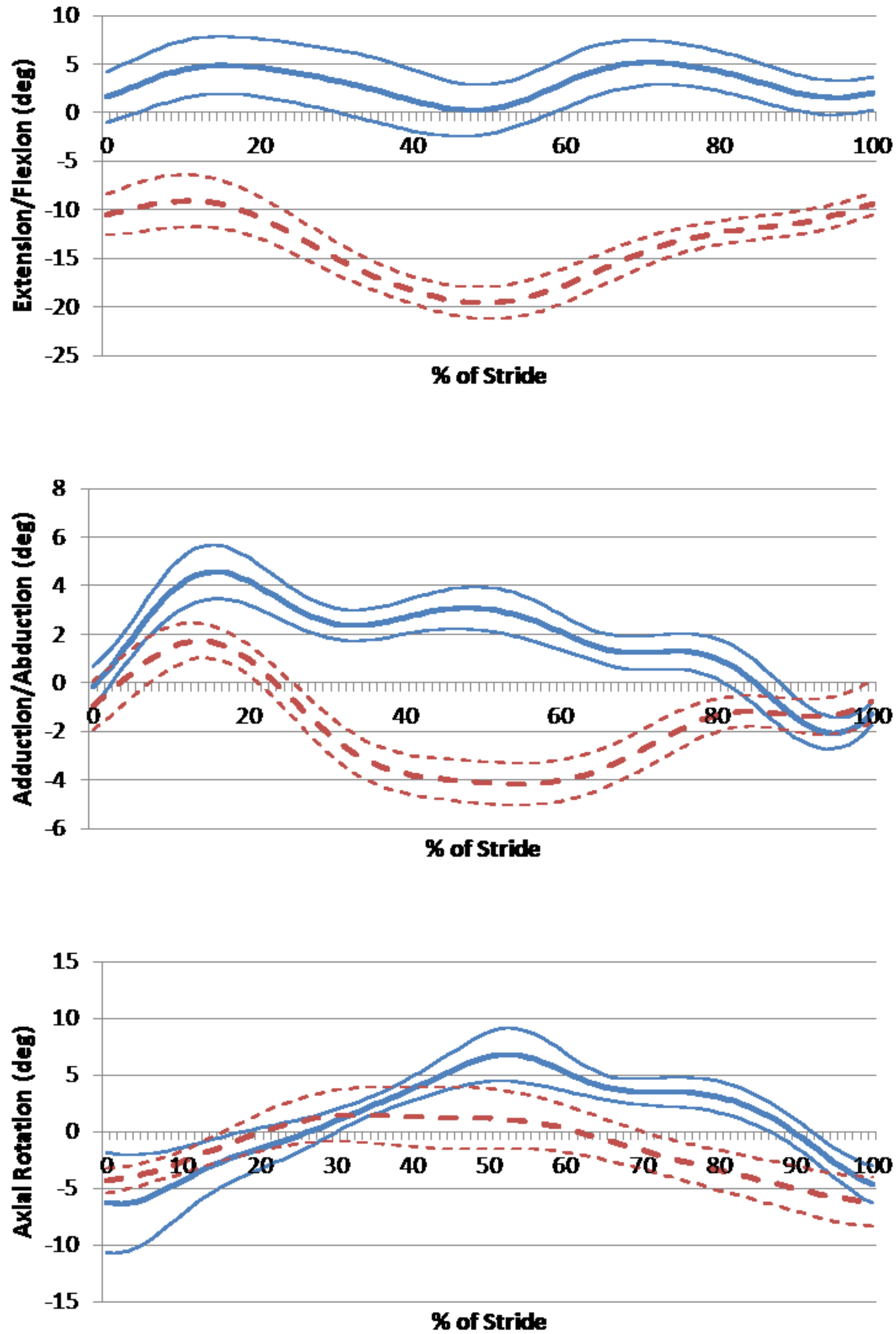


Figure 18: Mean and standard deviation curves from the median participant for the pelvis joint angular velocities on level ground. WP condition is solid lines and WOP condition is broken lines.

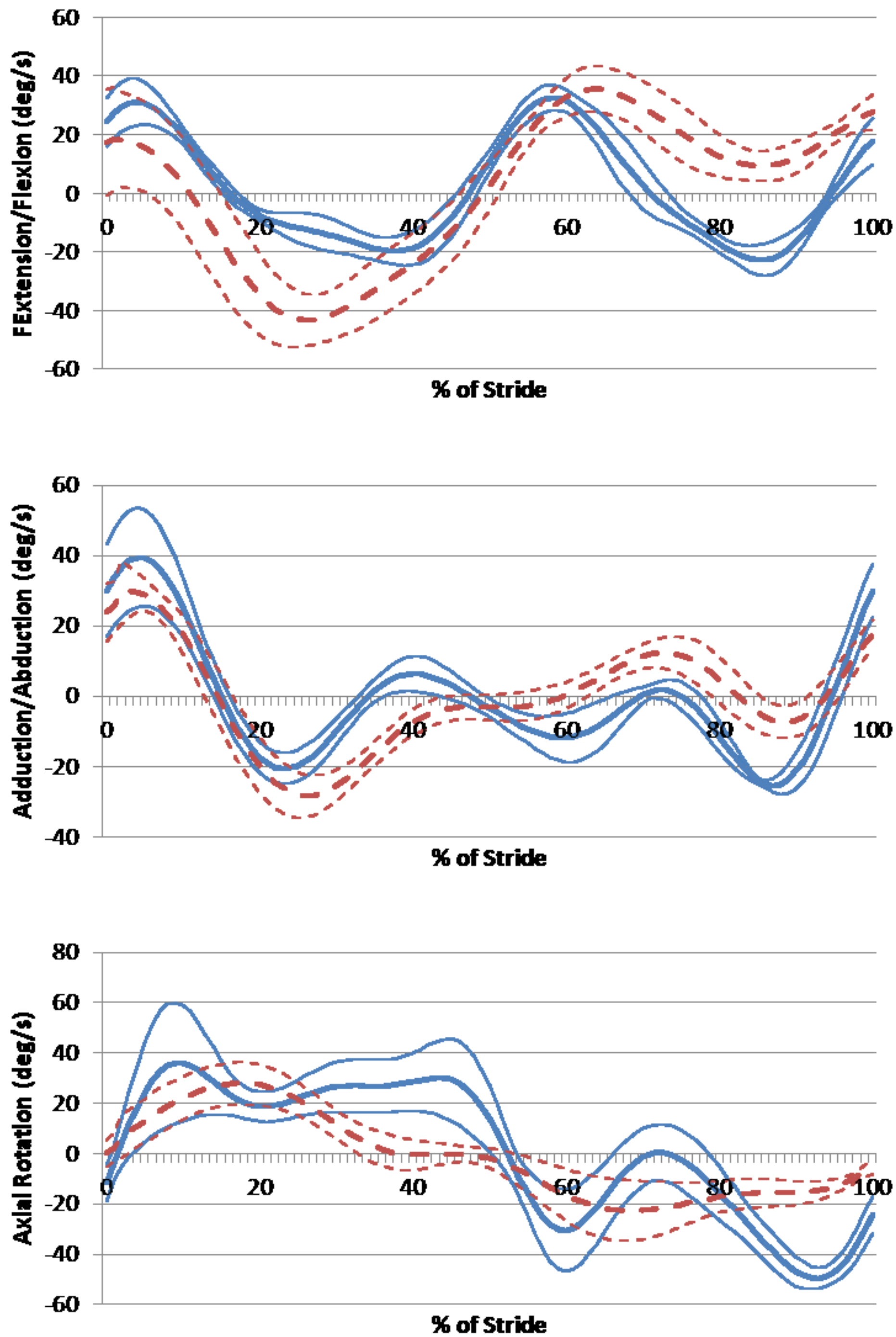


Figure 19: Mean and standard deviation curves from the median participant for the trunk joint angleson level ground. WP condition is solid lines and WOP condition is broken lines.

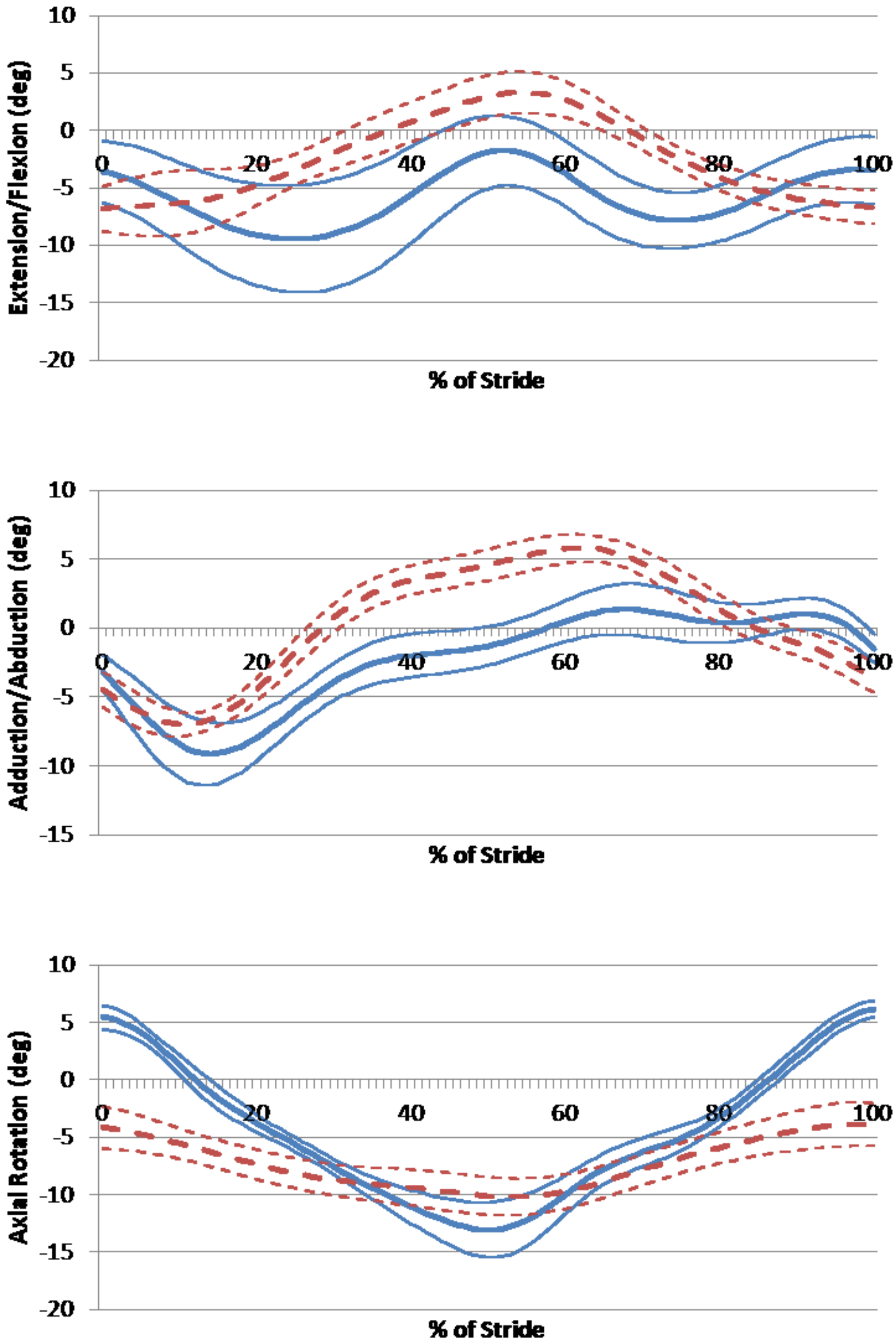


Figure 20: Mean and standard deviation curves from the median participant for the trunk joint angular velocitieson level ground. WP condition is solid lines and WOP condition is broken lines.

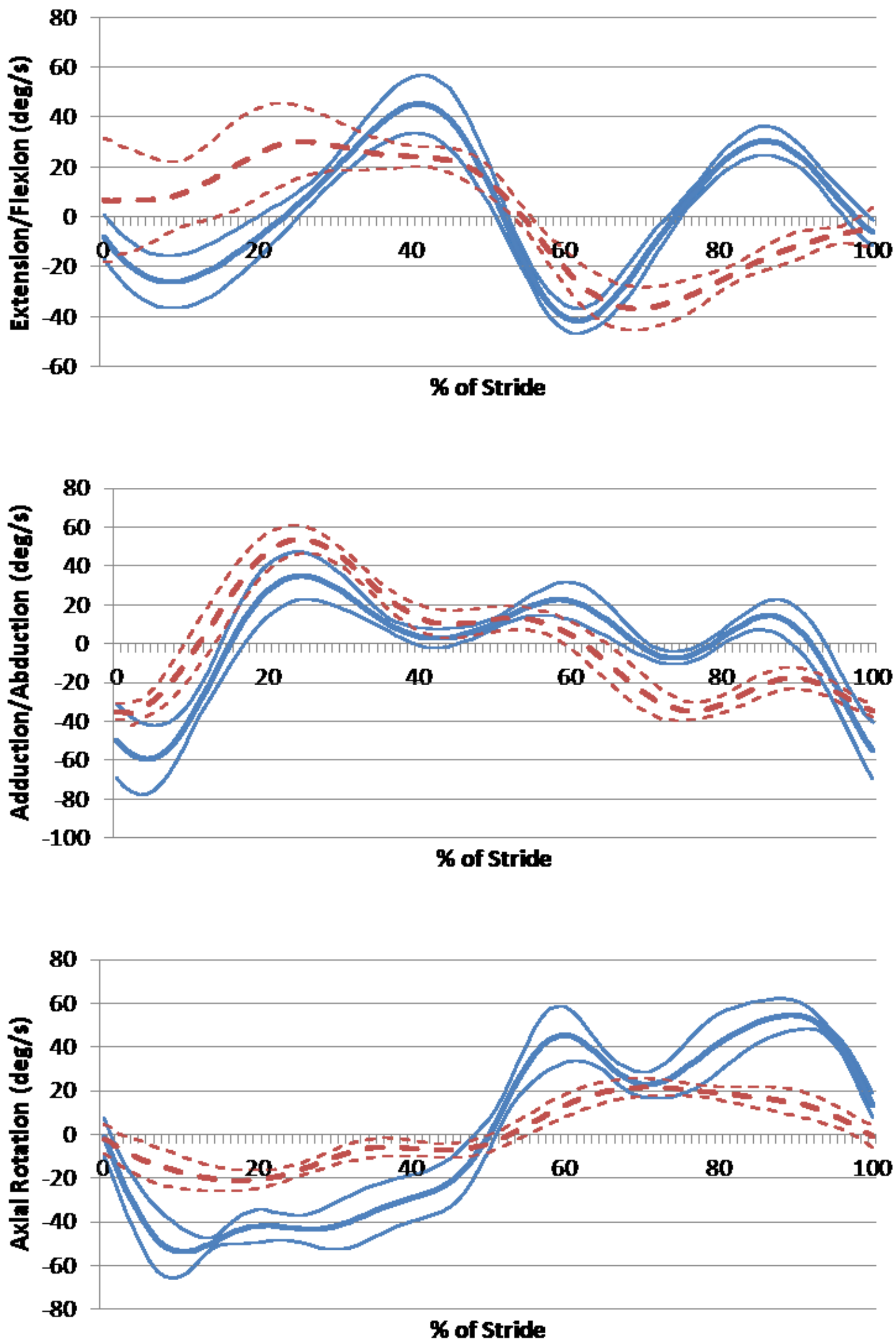


Figure 21: Mean and standard deviation curves from the median participant for the intact limb hip joint angles and angular velocities on level ground. WP condition is solid lines and WOP condition is broken lines.

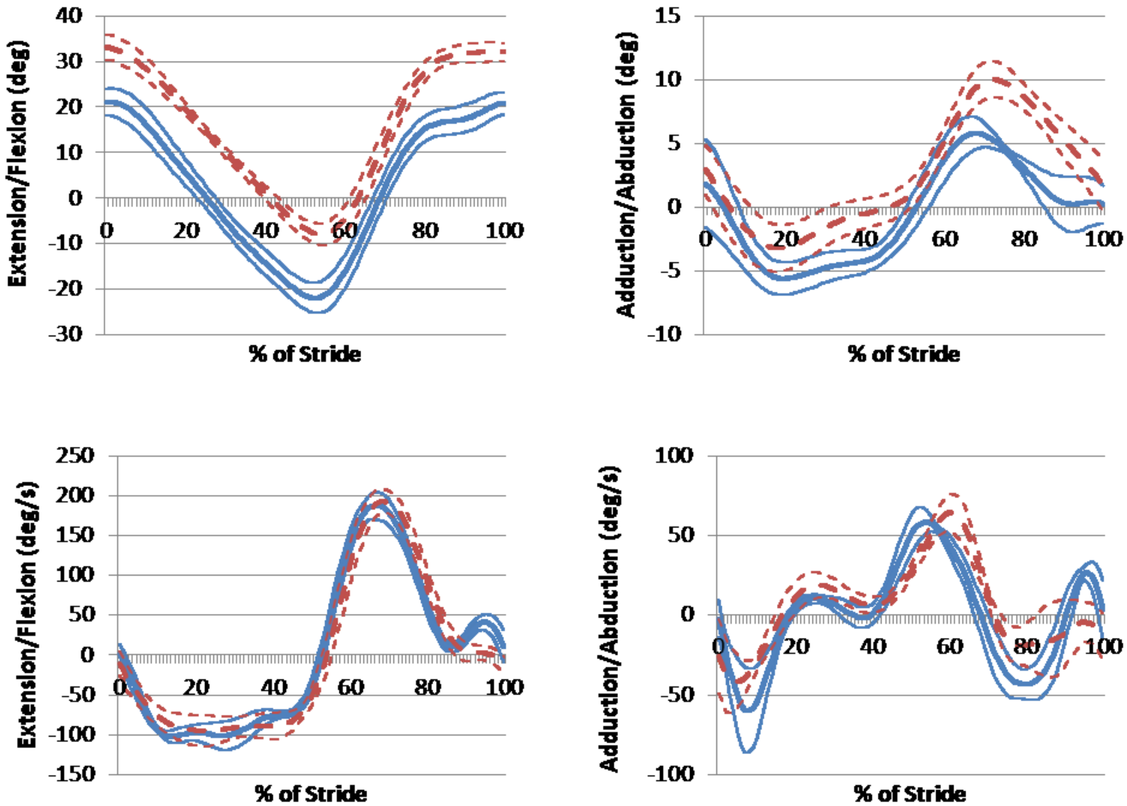


Figure 22: Mean and standard deviation curves from the median participant for the prosthetic limb hip joint angles and angular velocities on level ground. WP condition is solid lines and WOP condition is broken lines.

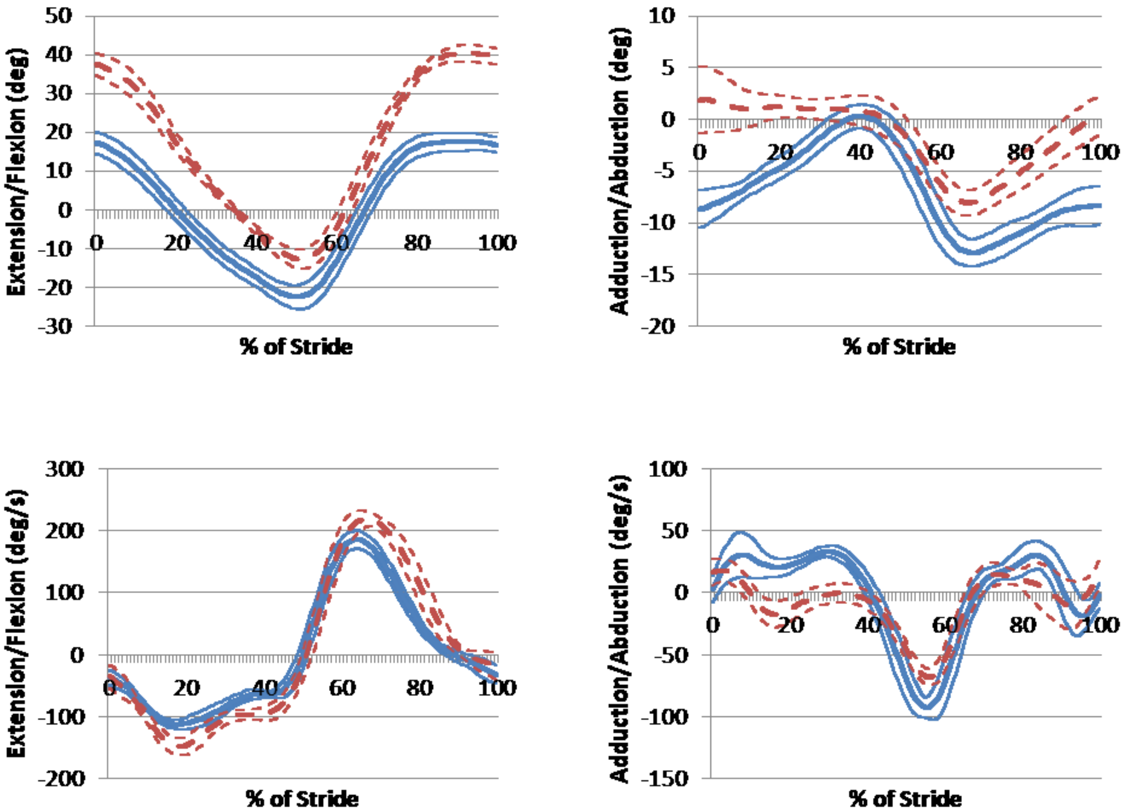


Figure 23: Mean and standard deviation curves from the median participant for the knee joint angles and angular velocities on level ground. WP condition is solid lines and WOP condition is broken lines.

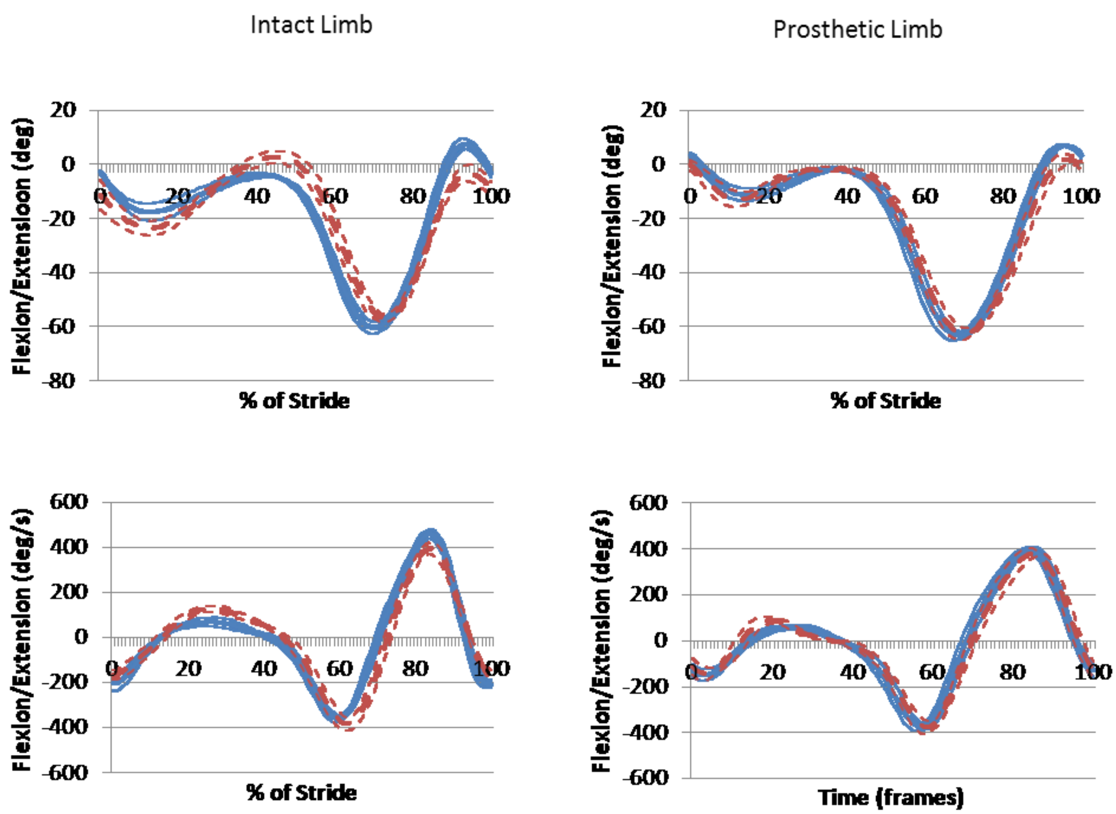


Figure 24: Mean and standard deviation curves from the median participant for the ankle joint angles and angular velocities on level ground. WP condition is solid lines and WOP condition is broken lines.

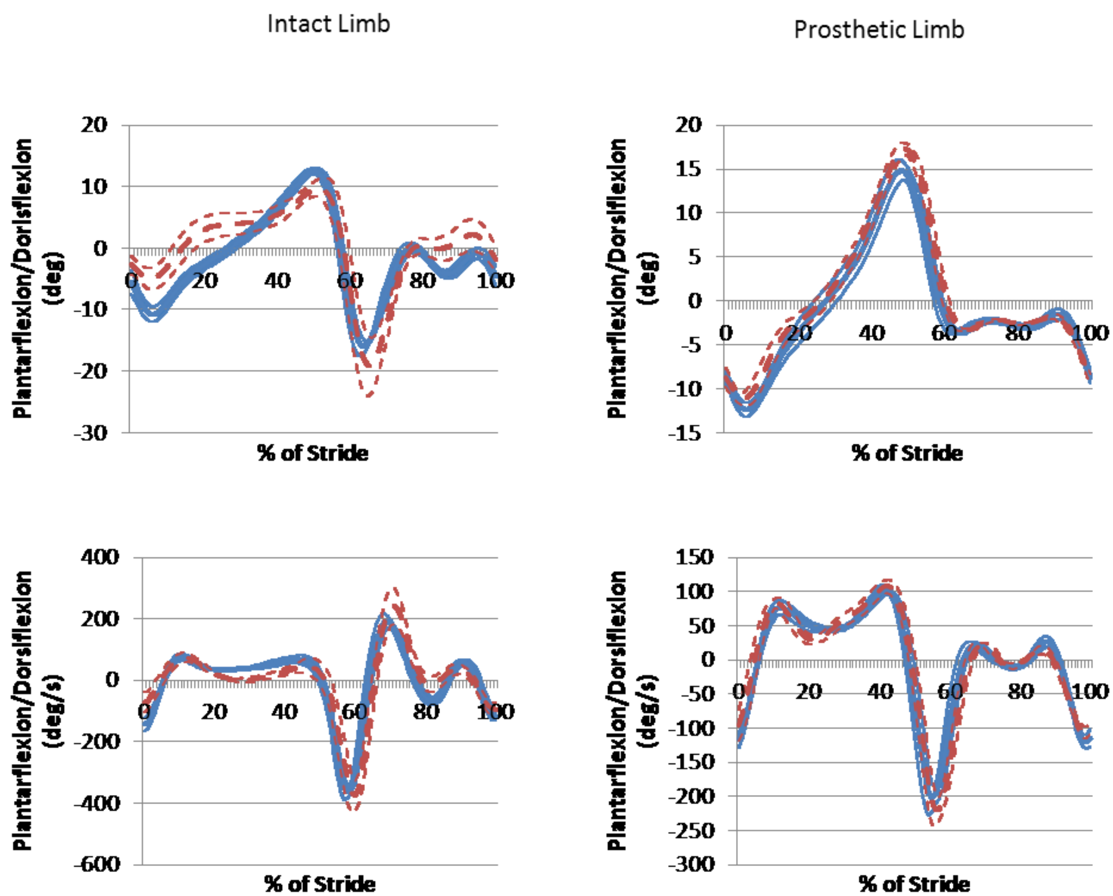


Figure 25: Mean and standard deviation curves from the median participant for the pelvis joint angleson uneven ground. WP condition is solid lines and WOP condition is broken lines.

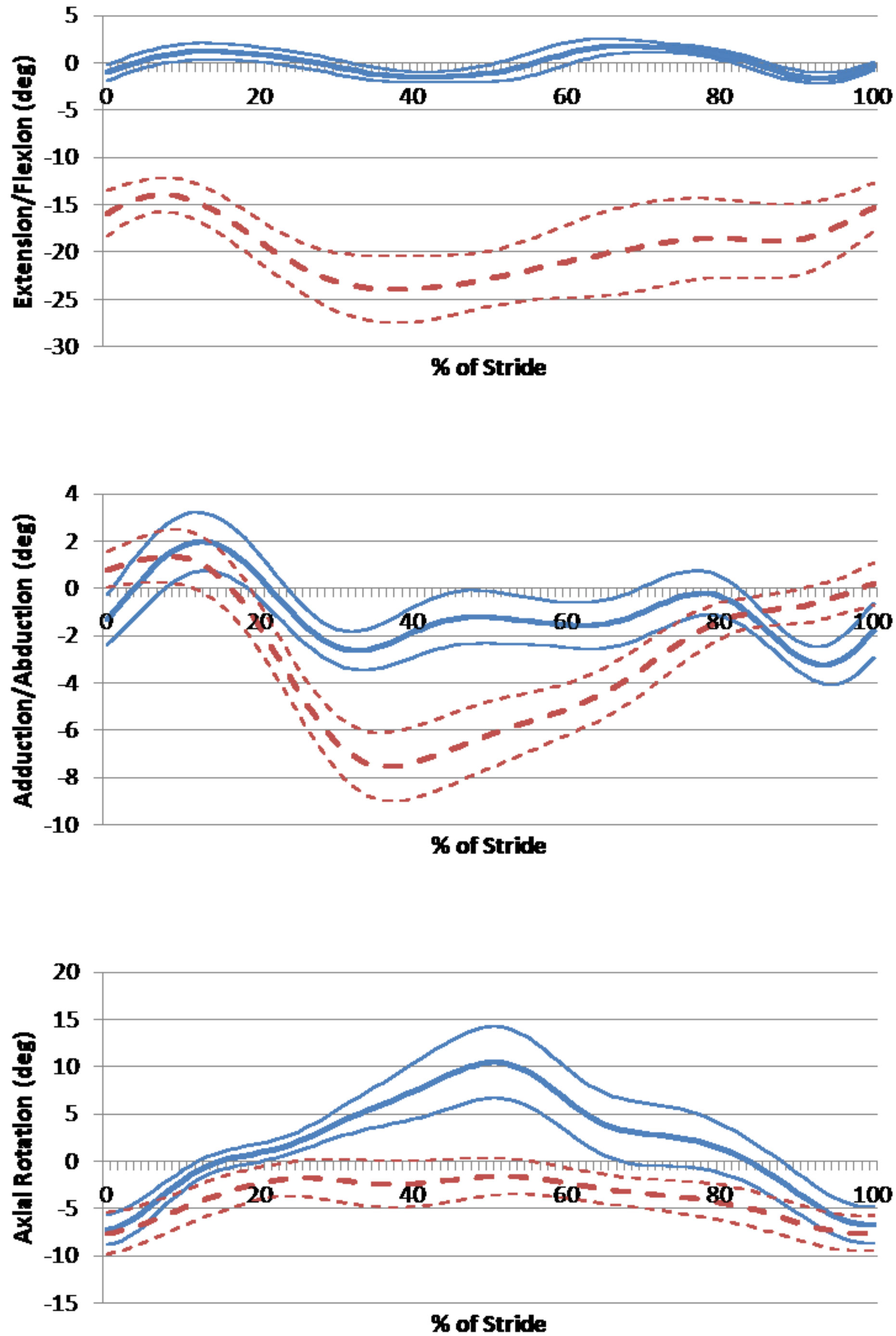


Figure 26: Mean and standard deviation curves from the median participant for the pelvis joint angular velocitieson uneven ground. WP condition is solid lines and WOP condition is broken lines.

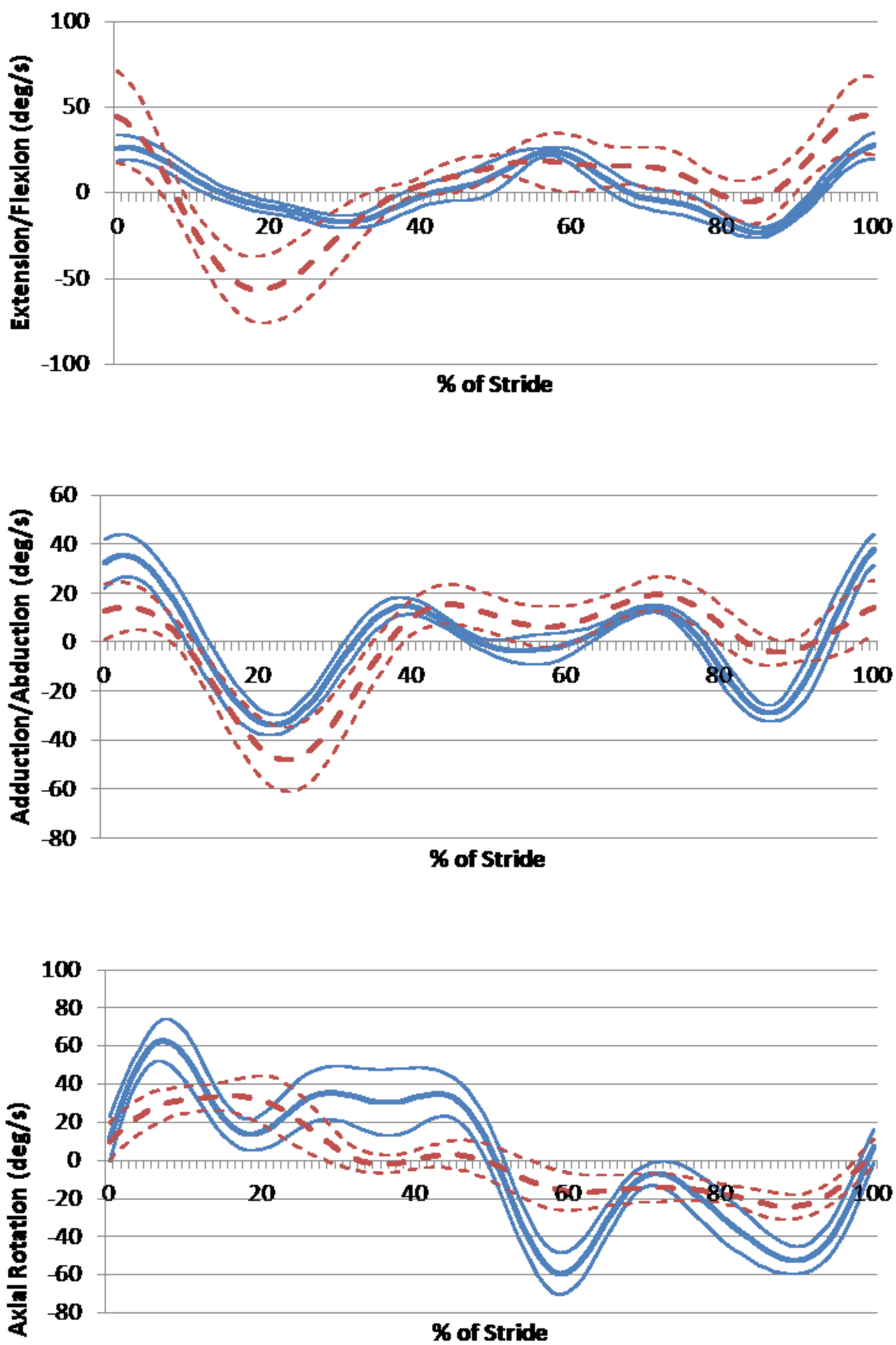


Figure 27: Mean and standard deviation curves from the median participant for the trunk joint angleson uneven ground. WP condition is solid lines and WOP condition is broken lines.

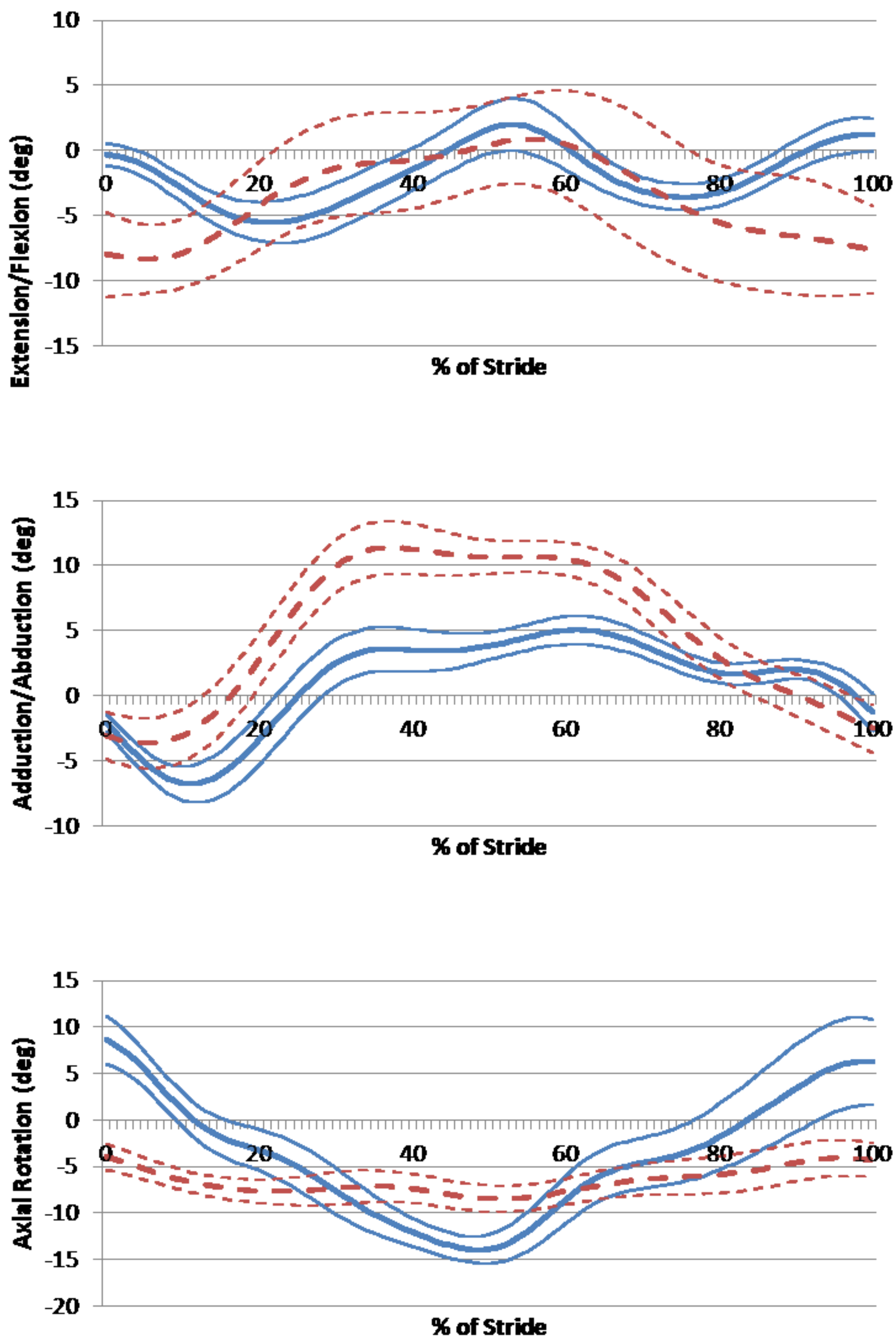


Figure 28: Mean and standard deviation curves from the median participant for the trunk joint angular velocities on uneven ground. WP condition is solid lines and WOP condition is broken lines.

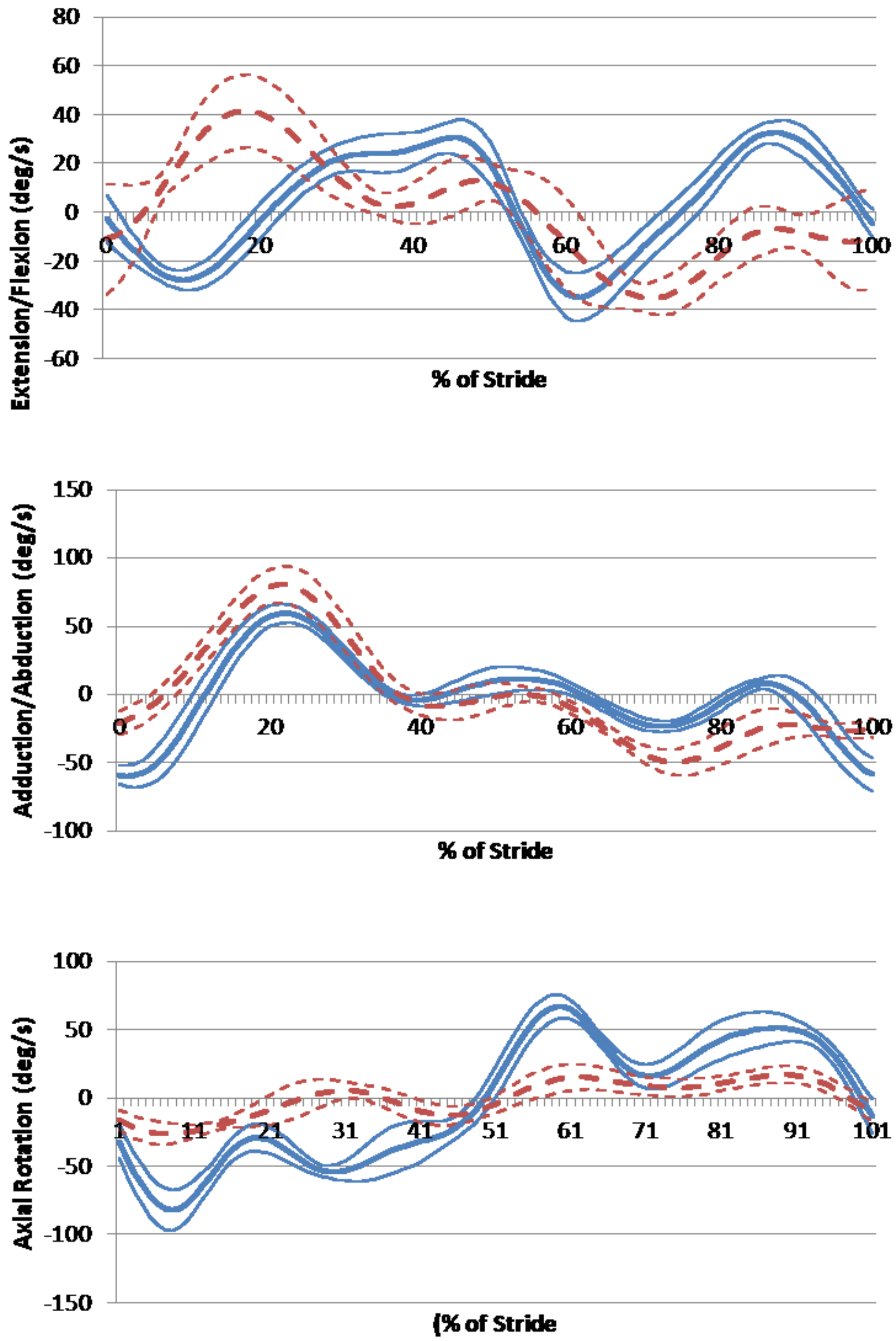


Figure 29: Mean and standard deviation curves from the median participant for the intact limb hip joint angles and angular velocities on uneven ground. WP condition is solid lines and WOP condition is broken lines.

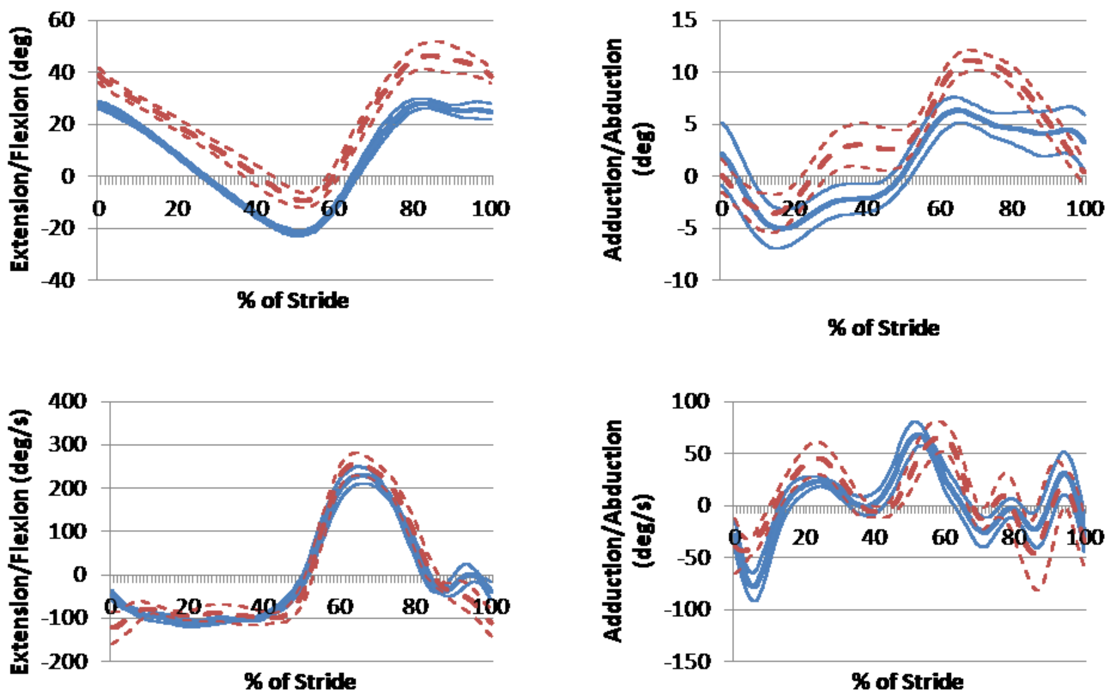


Figure 30: Mean and standard deviation curves from the median participant for the prosthetic limb hip joint angles and angular velocities on uneven ground. WP condition is solid lines and WOP condition is broken lines.

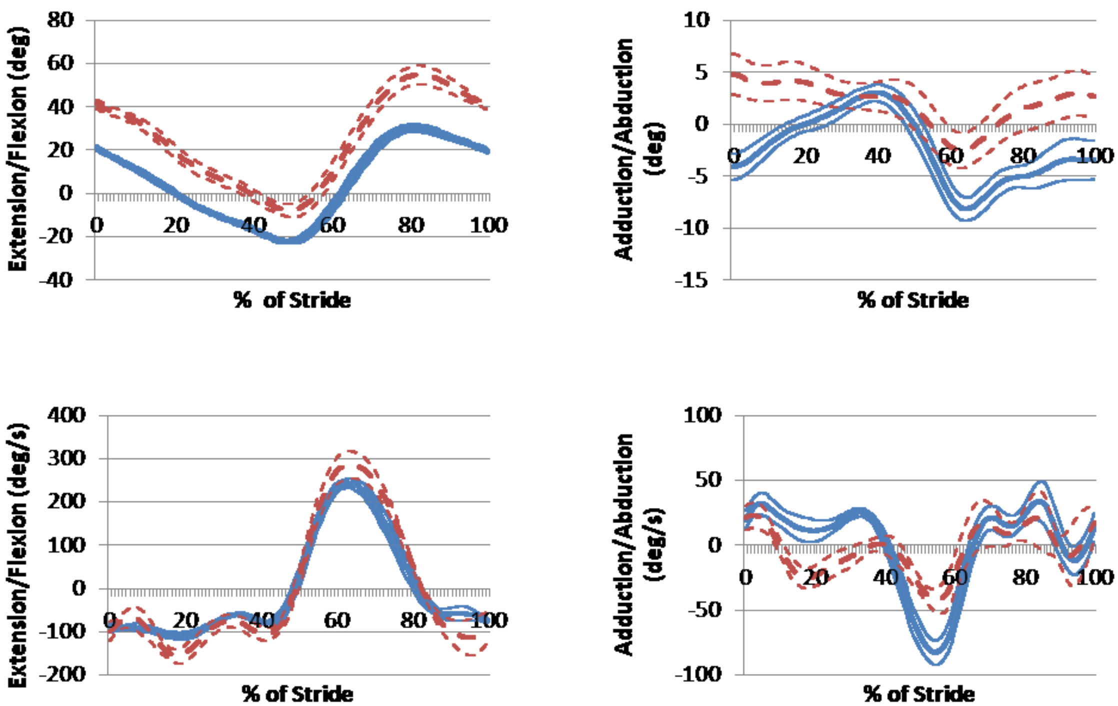


Figure 31: Mean and standard deviation curves from the median participant for the knee joint angles and angular velocities on uneven ground. WP condition is solid lines and WOP condition is broken lines.

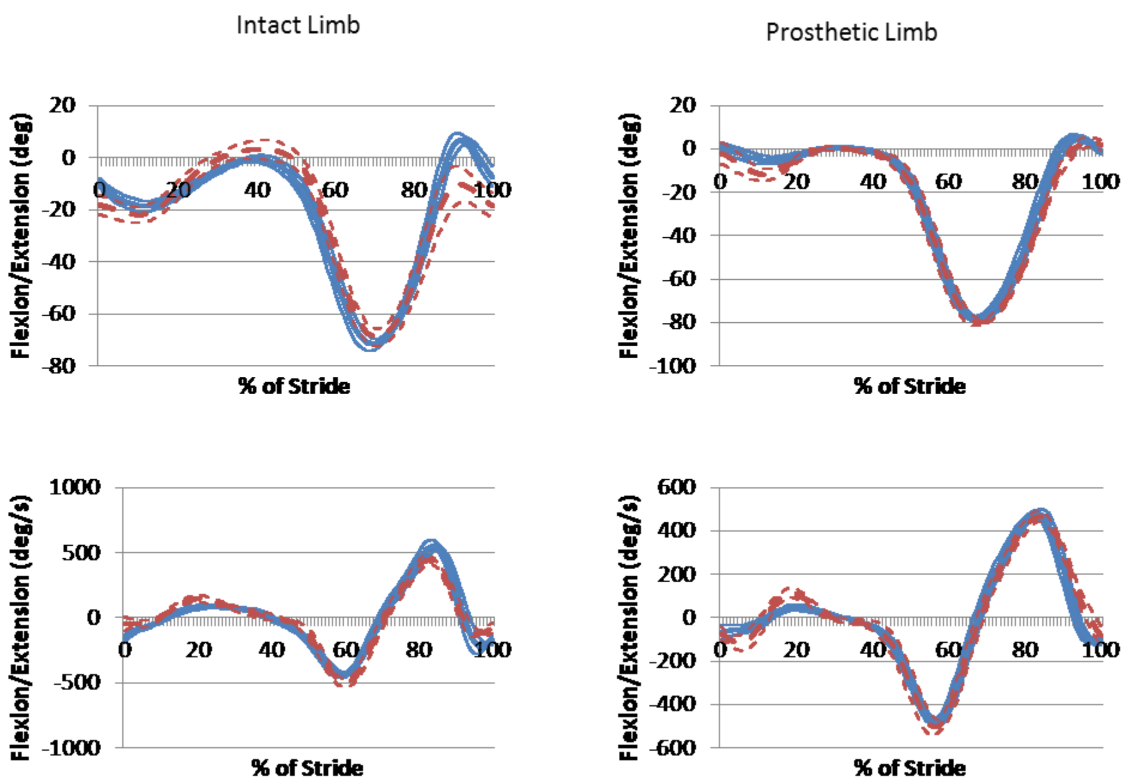


Figure 32: Mean and standard deviation curves from the median participant for the ankle joint angles and angular velocities on uneven ground. WP condition is solid lines and WOP condition is broken lines.

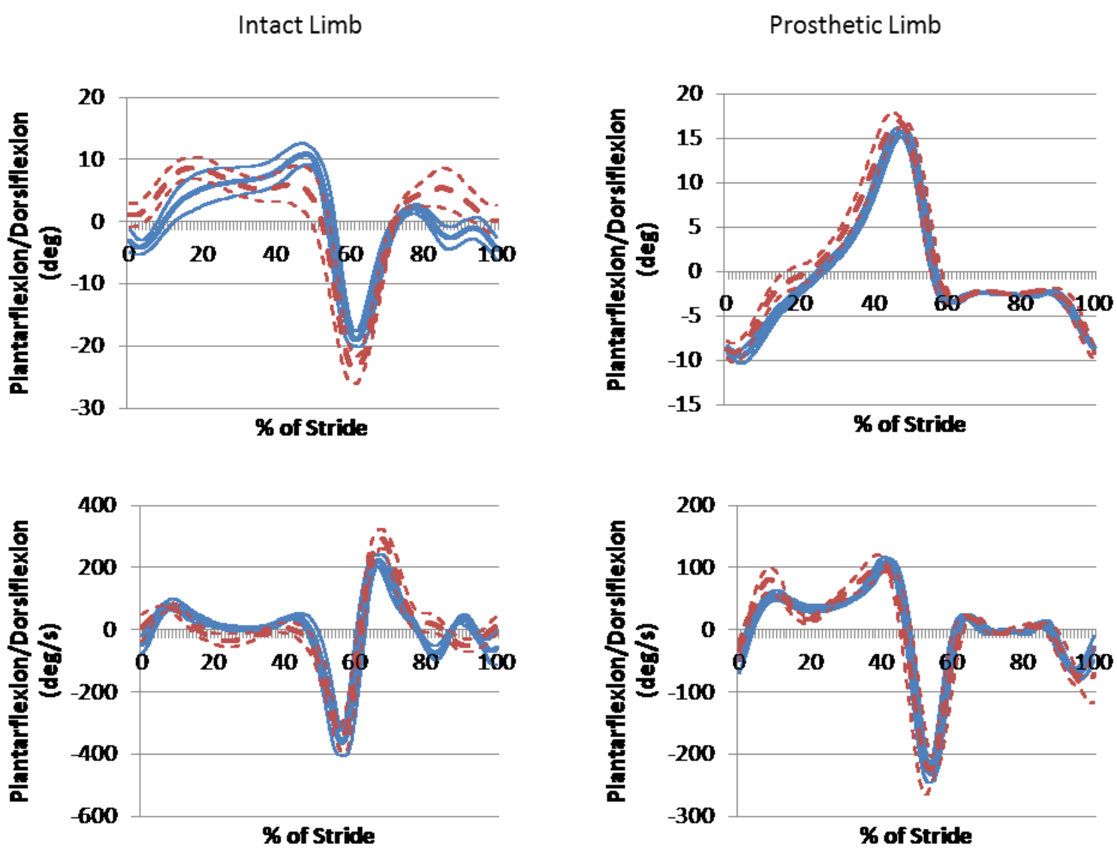


Figure 33: Mean and standard deviation curves from the median participant for the pelvis joint angleson ramp up. WP condition is solid lines and WOP condition is broken lines.

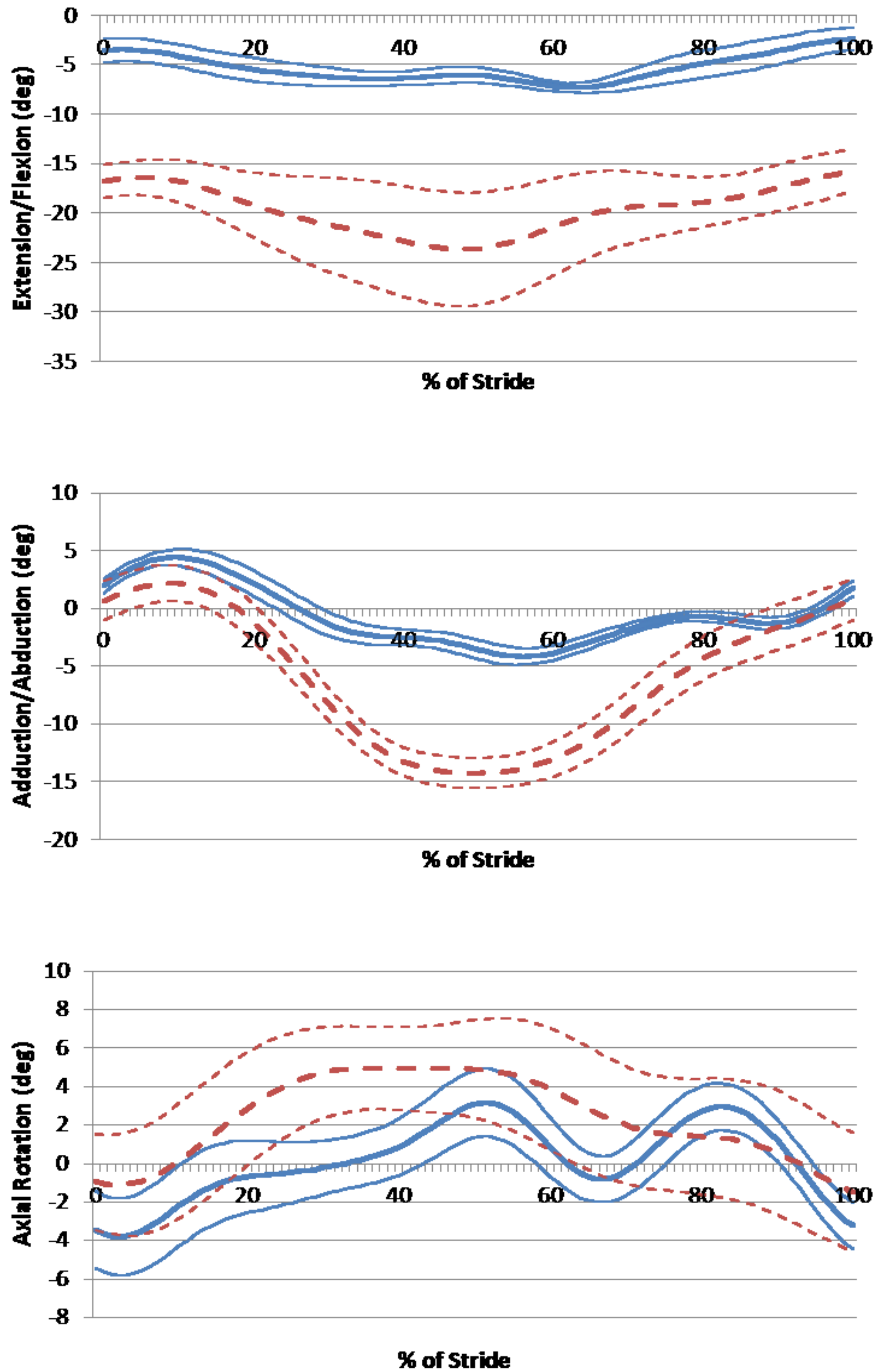


Figure 34: Mean and standard deviation curves from the median participant for the pelvis joint angular velocitieson ramp up. WP condition is solid lines and WOP condition is broken lines.

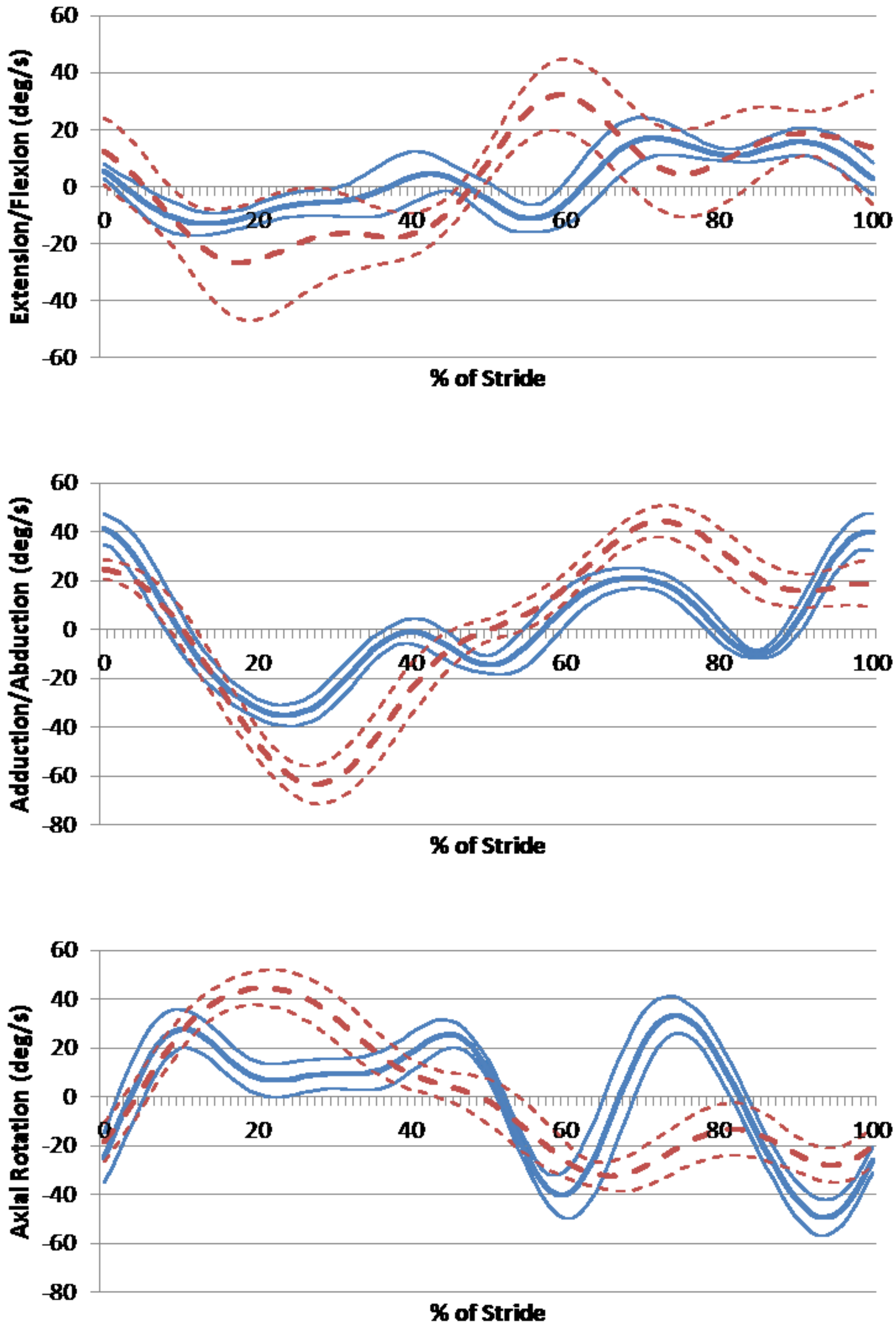


Figure 35: Mean and standard deviation curves from the median participant for the trunk joint angleson ramp up. WP condition is solid lines and WOP condition is broken lines.

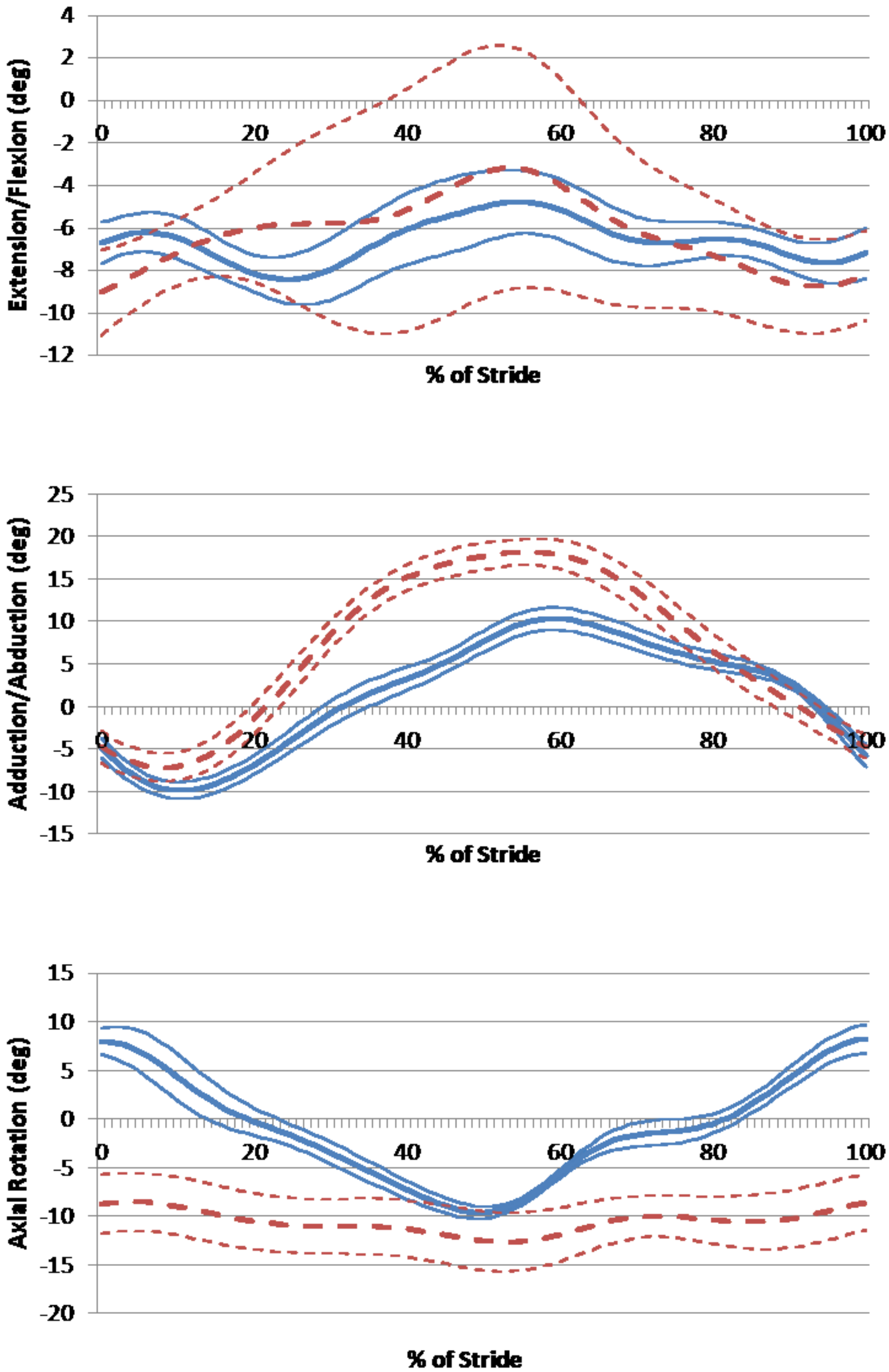


Figure 36: Mean and standard deviation curves from the median participant for the trunk joint angular velocitieson ramp up. WP condition is solid lines and WOP condition is broken lines.

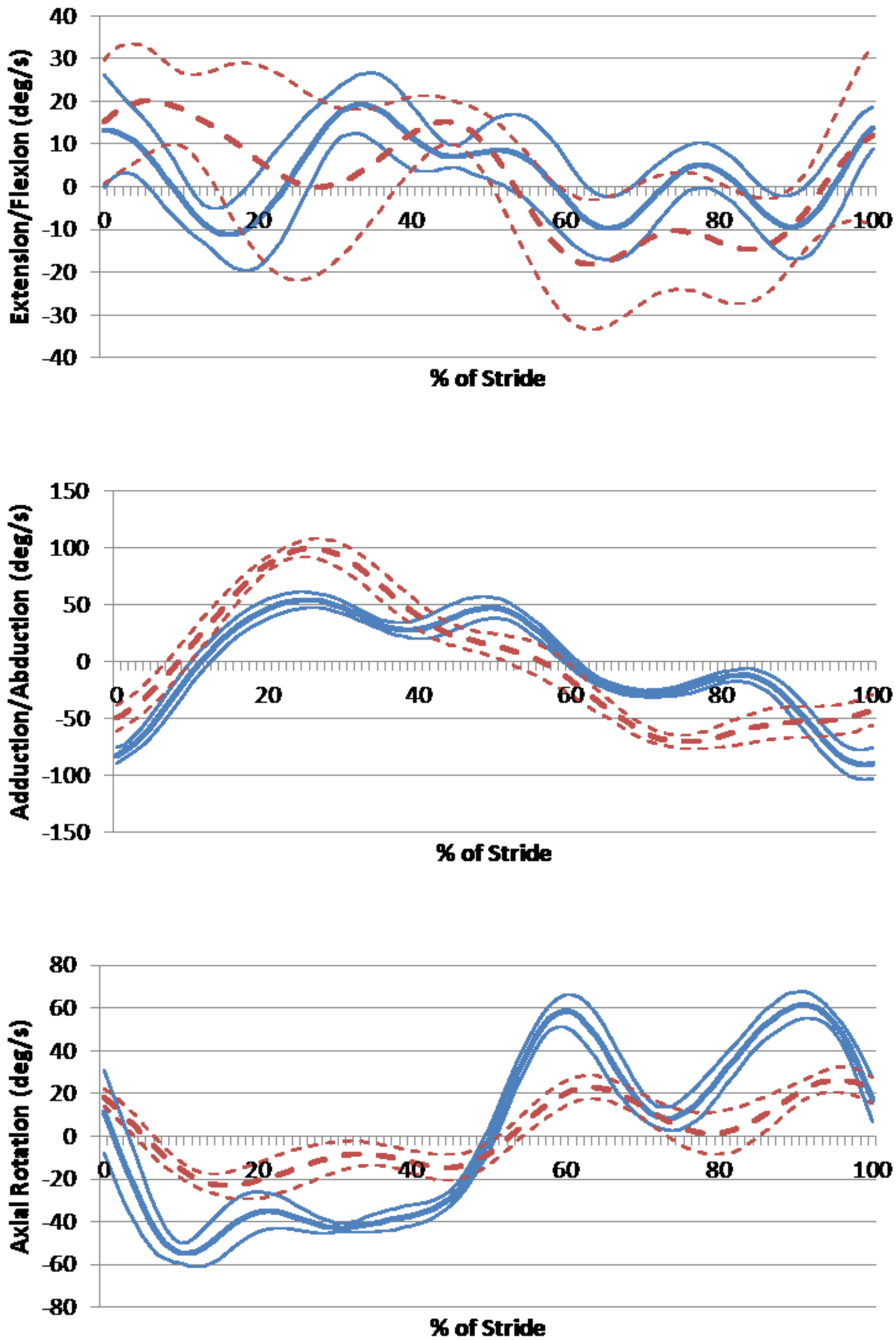


Figure 37: Mean and standard deviation curves from the median participant for the intact limb hip joint angles and angular velocities on ramp up. WP condition is solid lines and WOP condition is broken lines.

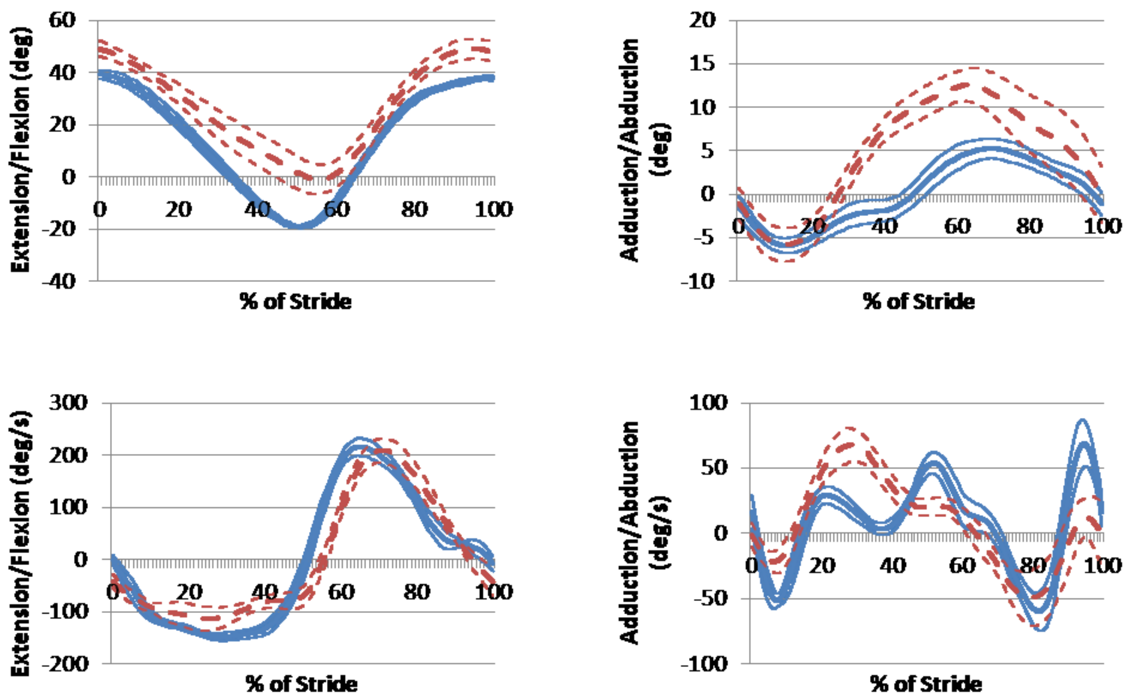


Figure 38: Mean and standard deviation curves from the median participant for the prosthetic limb hip joint angles and angular velocities on ramp up. WP condition is solid lines and WOP condition is broken lines.

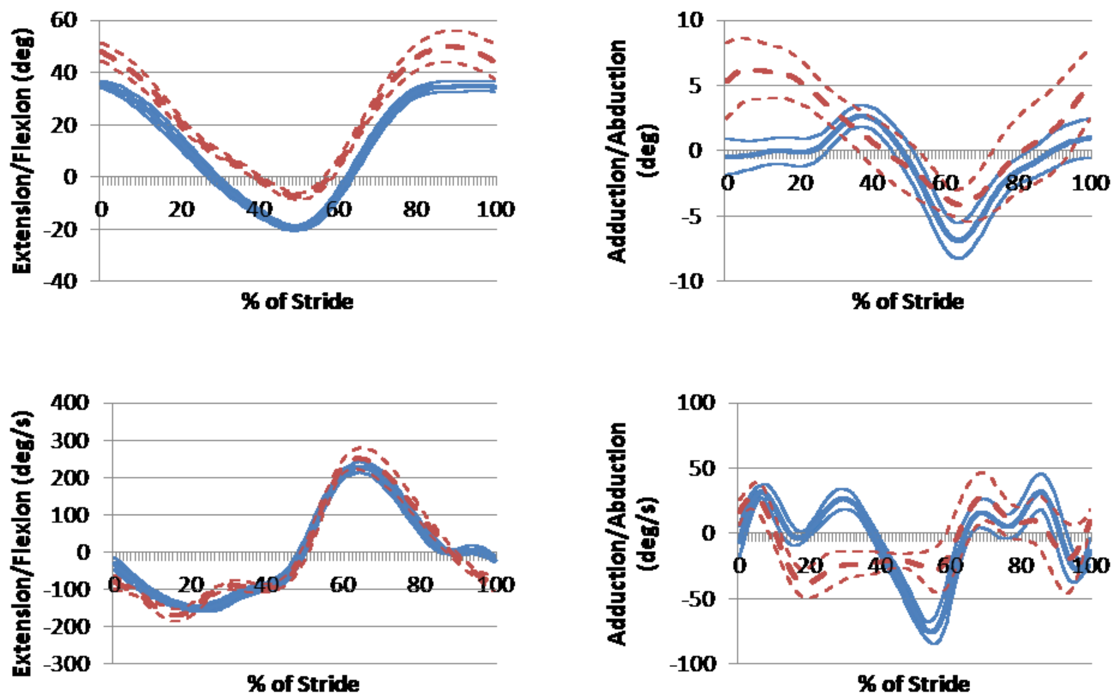


Figure 39: Mean and standard deviation curves from the median participant for the knee joint angles and angular velocities on ramp up. WP condition is solid lines and WOP condition is broken lines.

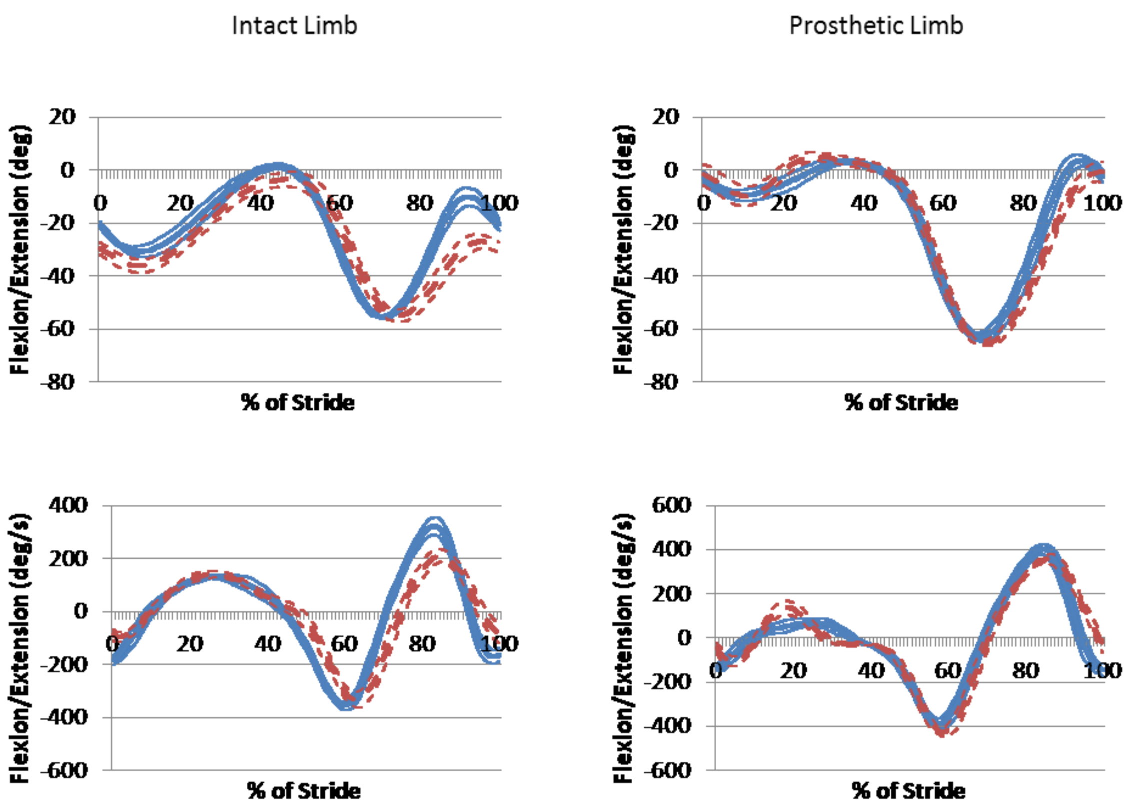


Figure 40: Mean and standard deviation curves from the median participant for the ankle joint angles and angular velocities on ramp up. WP condition is solid lines and WOP condition is broken lines.

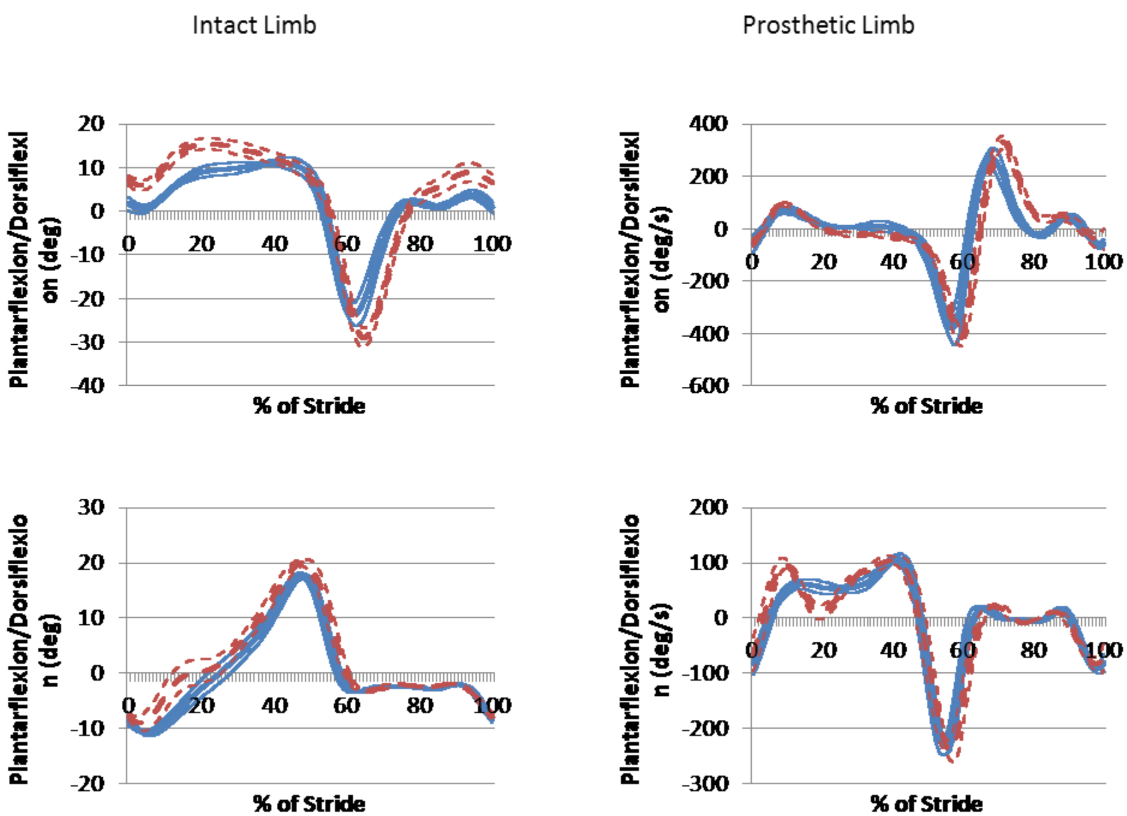
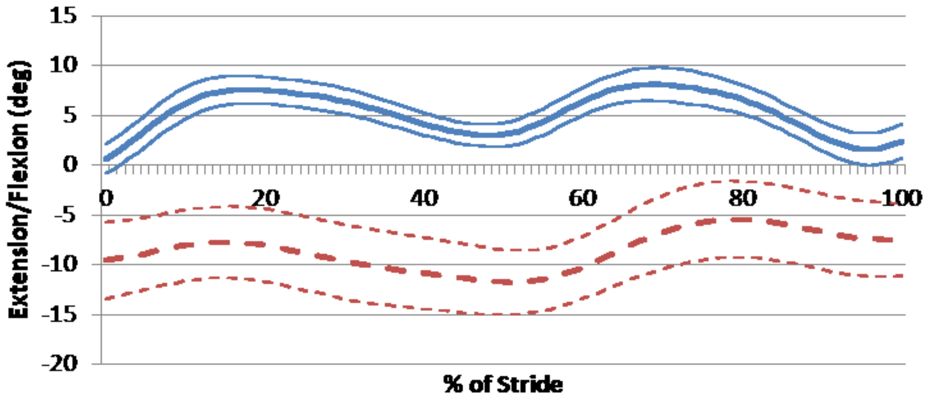
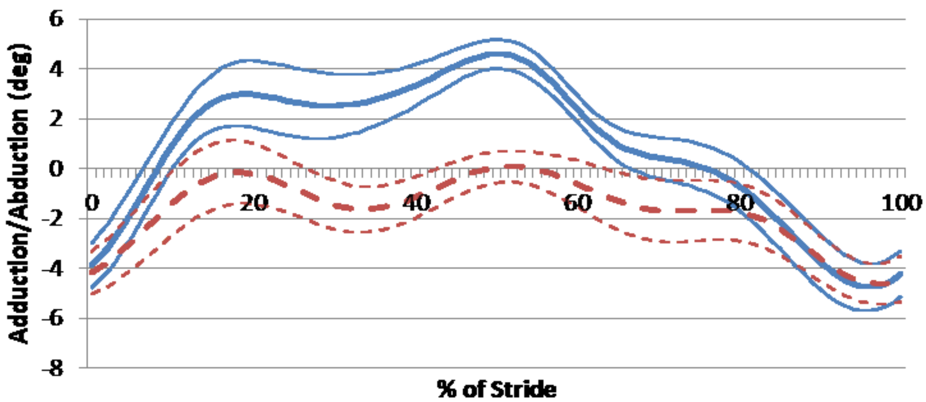


Figure 41: Mean and standard deviation curves from the median participant for the pelvis joint angleson ramp down. WP condition is solid lines and WOP condition is broken lines.





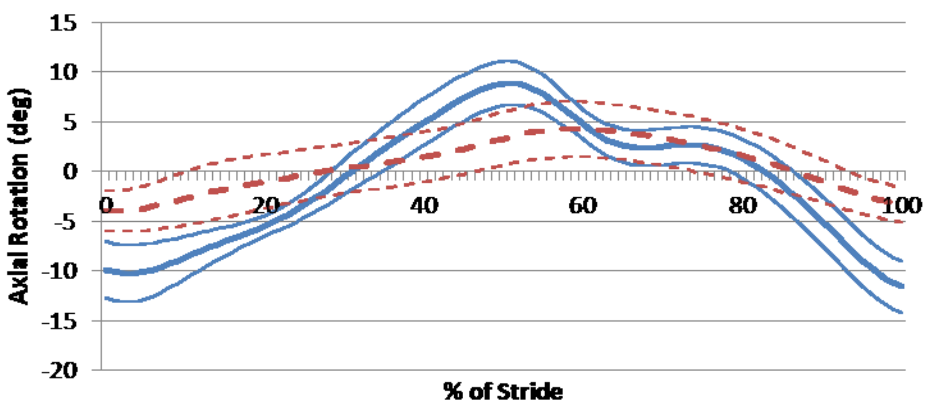


Figure 42: Mean and standard deviation curves from the median participant for the pelvis joint angular velocitieson ramp down. WP condition is solid lines and WOP condition is broken lines.

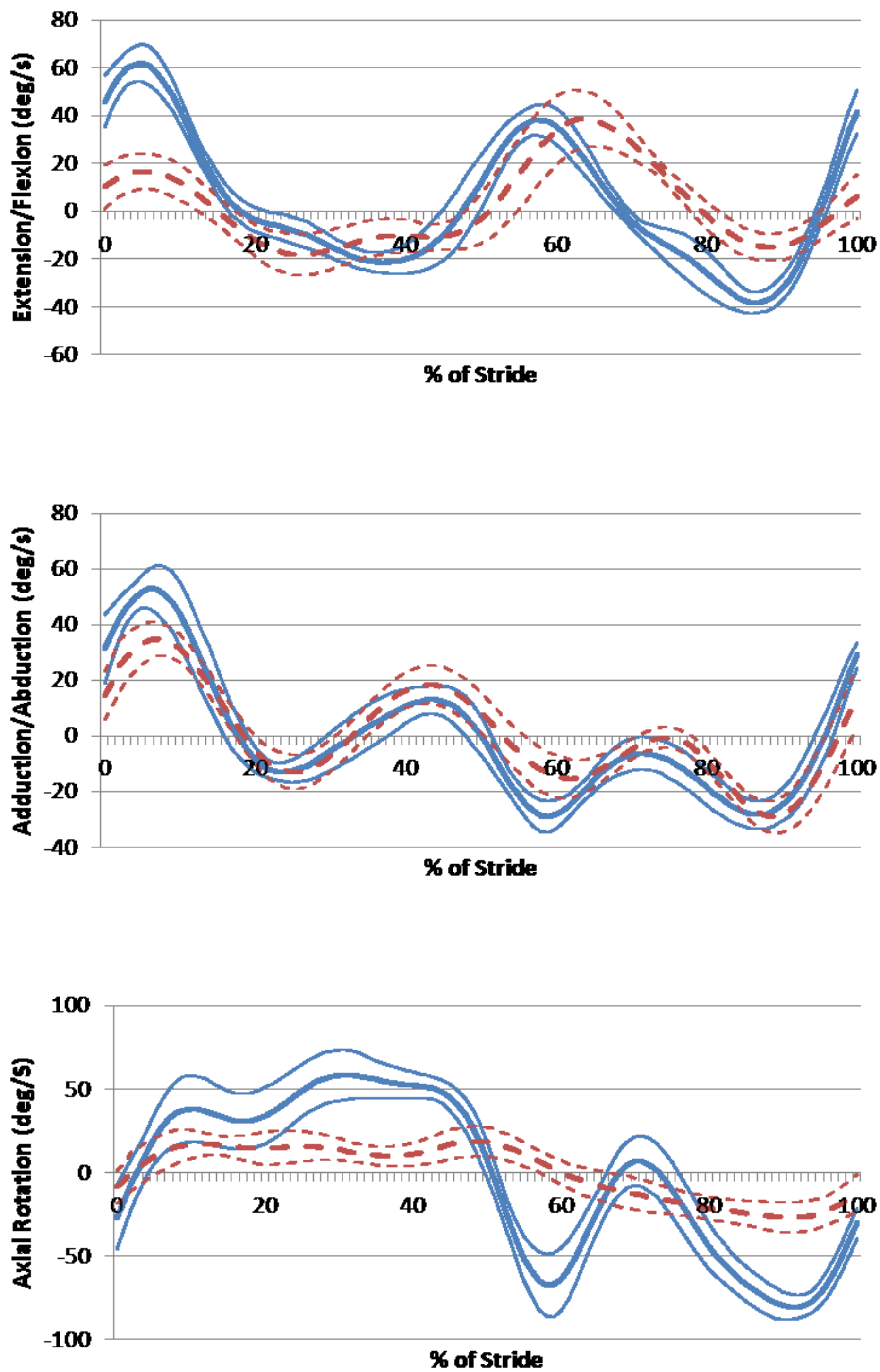


Figure 43: Mean and standard deviation curves from the median participant for the trunk joint angleson ramp down. WP condition is solid lines and WOP condition is broken lines.

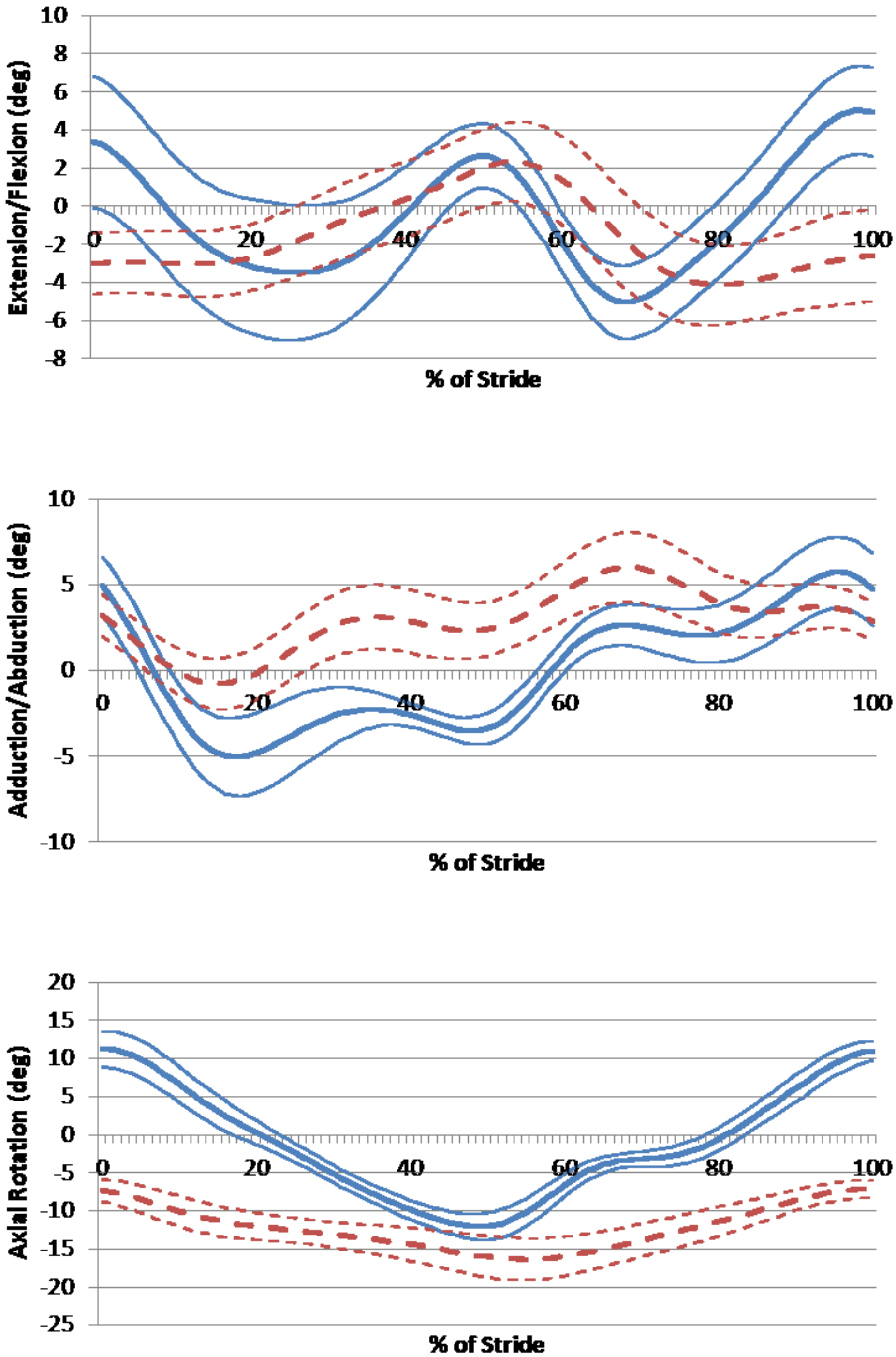


Figure 44: Mean and standard deviation curves from the median participant for the trunk joint angular velocitieson ramp down. WP condition is solid lines and WOP condition is broken lines.

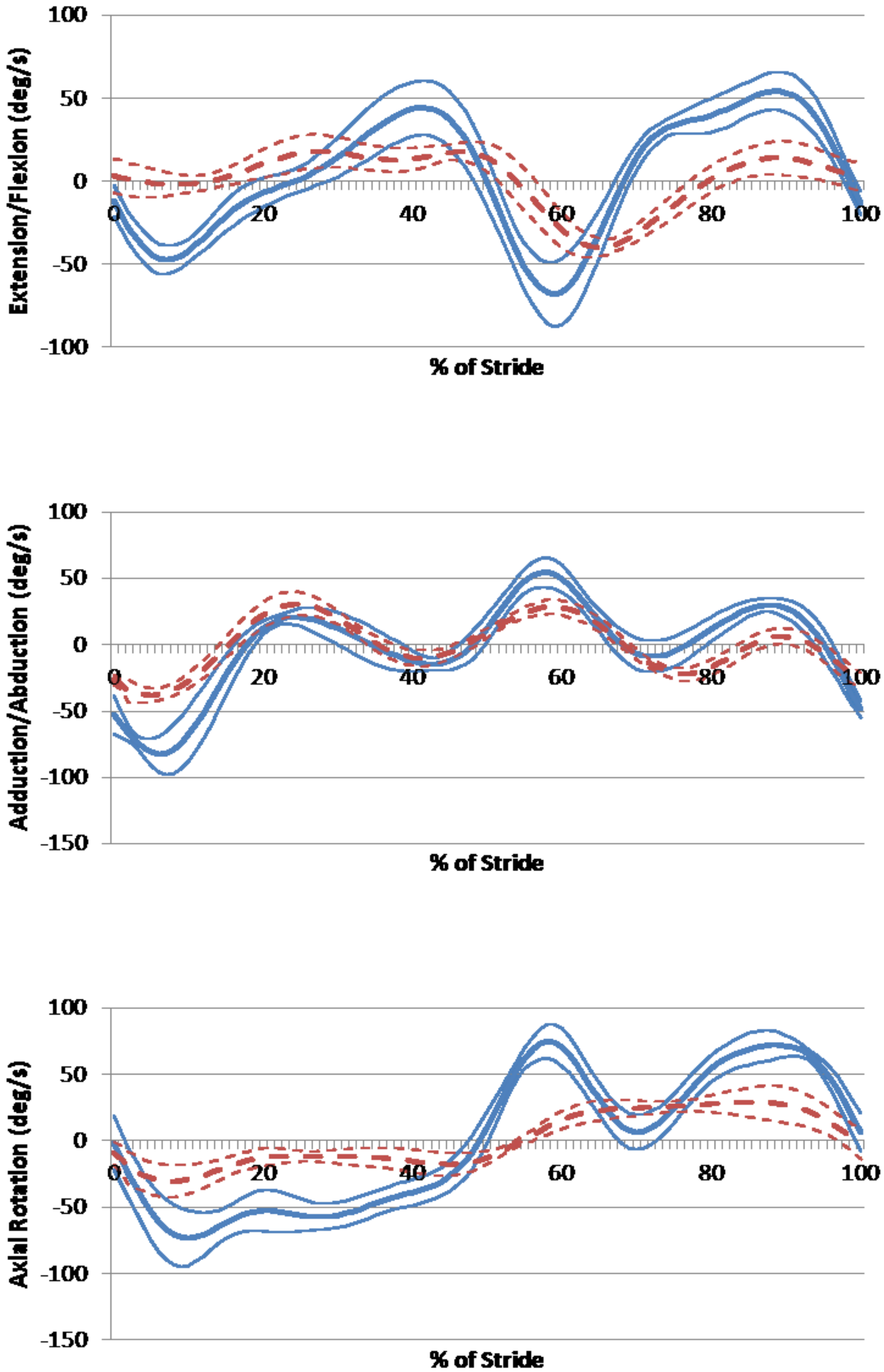


Figure 45: Mean and standard deviation curves from the median participant for the intact limb hip joint angles and angular velocities on ramp down. WP condition is solid lines and WOP condition is broken lines.

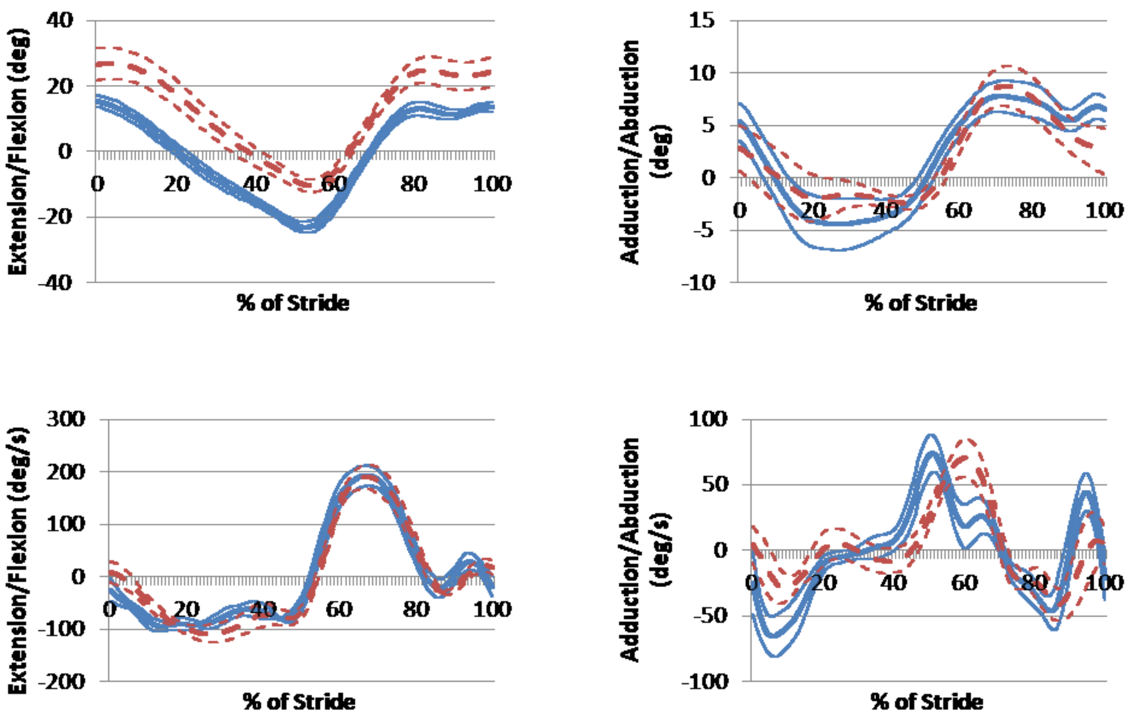


Figure 46: Mean and standard deviation curves from the median participant for the prosthetic limb hip joint angles and angular velocities on ramp down. WP condition is solid lines and WOP condition is broken lines.

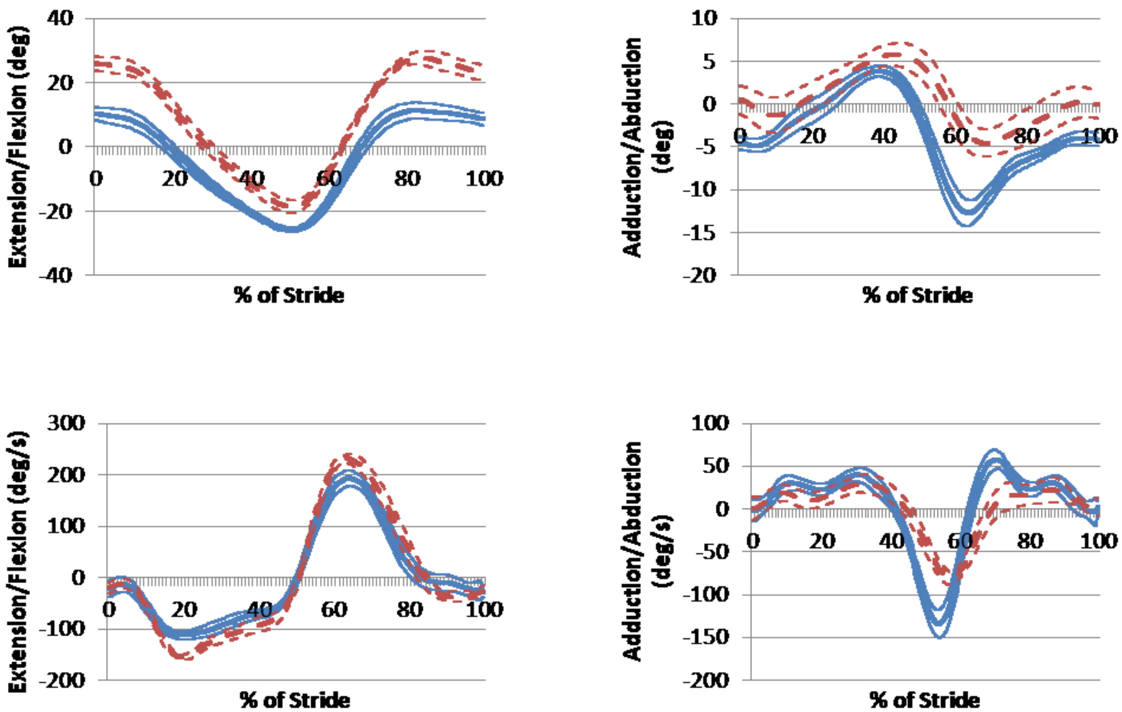


Figure 47: Mean and standard deviation curves from the median participant for the knee joint angles and angular velocities on ramp down. WP condition is solid lines and WOP condition is broken lines.

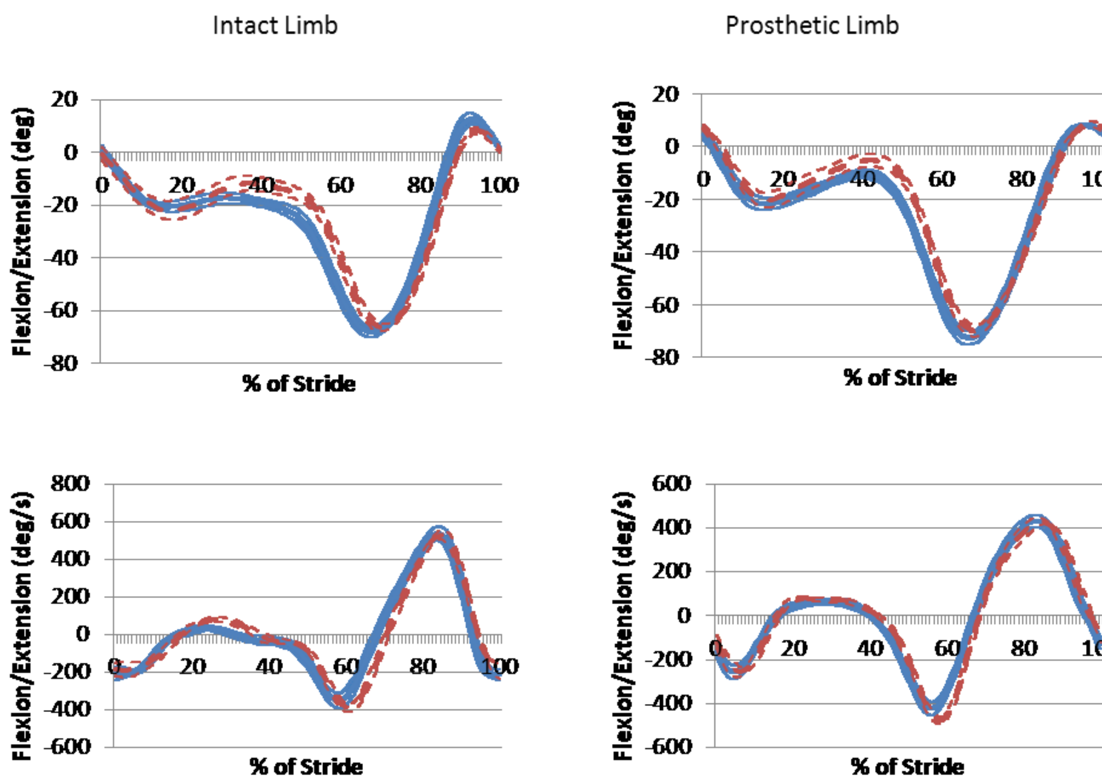


Figure 48: Mean and standard deviation curves from the median participant for the ankle joint angles and angular velocities on ramp down. WP condition is solid lines and WOP condition is broken lines.

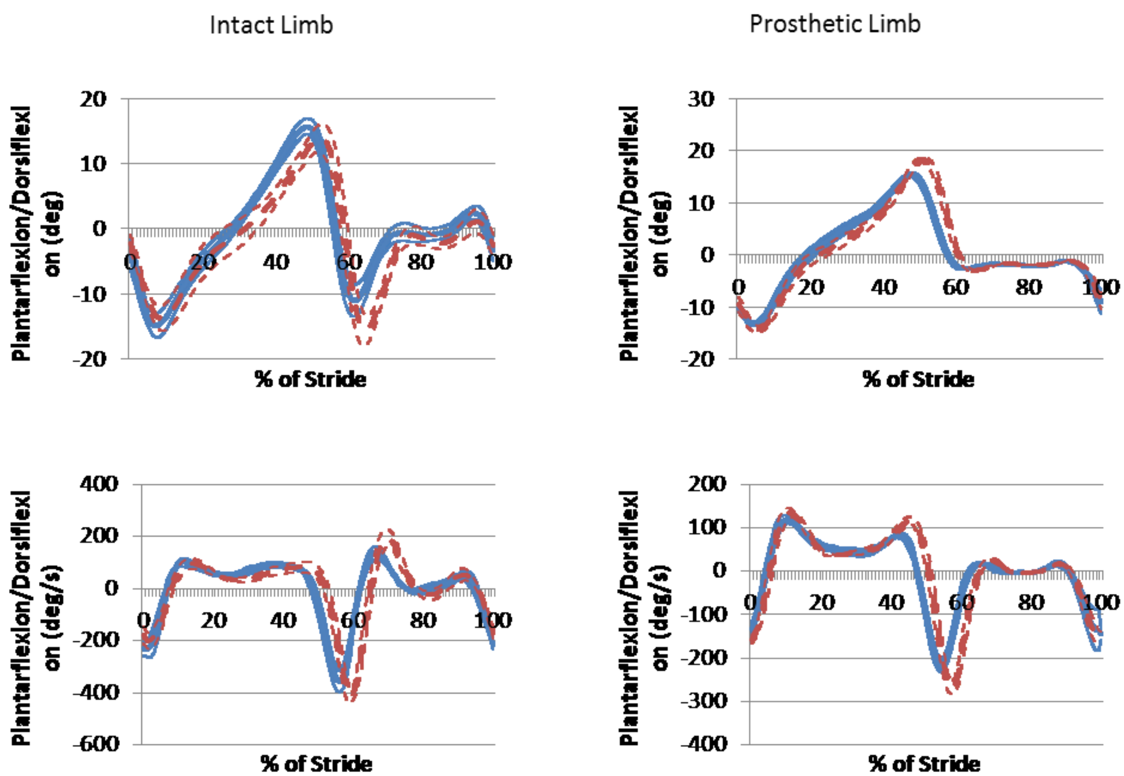


Figure 49: Mean and standard deviation curves from the median participant for the hip moment and power on level ground. WP condition is solid lines and WOP condition is broken lines.

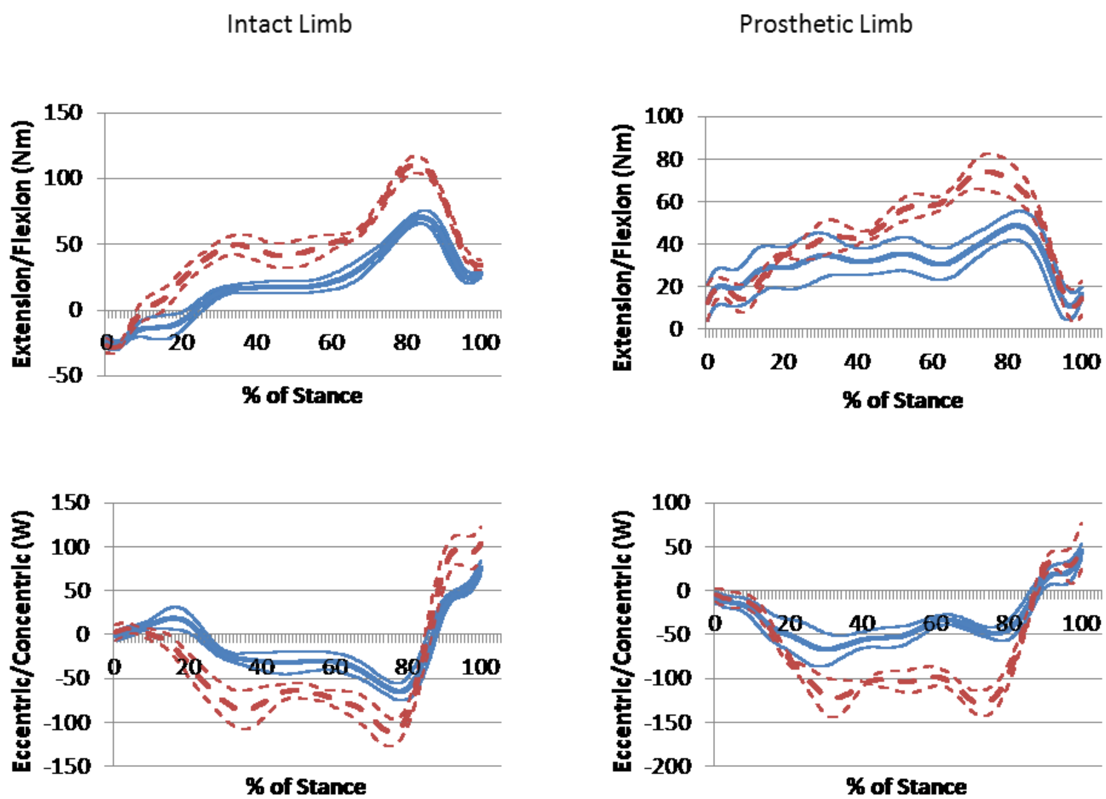


Figure 50: Mean and standard deviation curves from the median participant for the knee moment and power on level ground. WP condition is solid lines and WOP condition is broken lines.

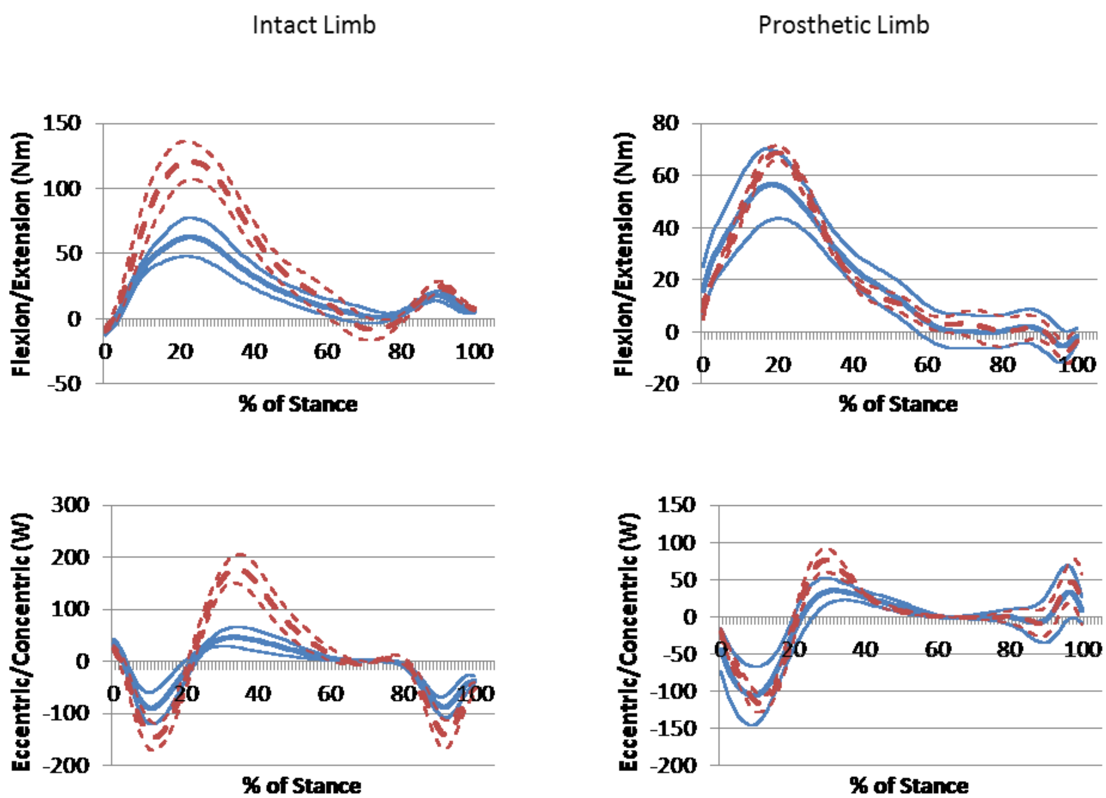


Figure 51: Mean and standard deviation curves from the median participant for the ankle moment and power on level ground. WP condition is solid lines and WOP condition is broken lines.